FEB 2 4 1932

Medical Lib.

Volume XIV FEBRUARY, 1932 Number 2

THE JOURNAL OF INDUSTRIAL HYGIENE

WITH ABSTRACT OF THE LITERATURE

Editor, United States
DAVID L. EDSALL, M.D., S.D.

Honorary Consulting Editor
SIR THOMAS M. LEGGE, M.D., D.P.H.

Editor, Great Britain
E. L. COLLIS, M.D., M.R.C.S.

The Baltimore Gas Appliance Ordinance and its Relation to Public Health

A Pressure Chamber Installation for Studying the Physiologic Effects of Pressures Varying from Six to Sixty Pounds per Square Inch Absolute

Control of the Silicosis Hazard in the Hard Rock Industries. II. An Investigation of the Kelley Dust Trap for Use with Pneumatic Rock Drills of the "Jackhamer" Type

Published at Mount Royal and Guilford Aves., Baltimore, Md.
by HARVARD SCHOOL OF PUBLIC HEALTH

Entered as second-class matter, at the Post Office at Baltimore, Maryland, under Act of March 3, 1879.
Copyright, 1932, by Harvard Medical School

Made in the United States of America

EDITORS

United States
DAVID L. EDSALL, M.D., S.D.

Great Britain
E. L. COLLIS, M.D., M.R.C.S.

HONORARY CONSULTING EDITOR
SIR THOMAS M. LEGGE, M.D., D.P.H.

ASSOCIATE EDITORS

United States

W. IRVING CLARK, JR., M.D.
ALICE HAMILTON, A.M., M.D.
EMERY R. HAYHURST, A.M., Ph.D., M.D.
YANDELL HENDERSON, Ph.D.
JAMES P. LEAKE, M.D.
WALTER R. MILES, Ph.D.
HARRY E. MOCK, M.D.
C.-E. A. WINSLOW, M.S., A.M., Dr.P.H.
WILLIAM P. YANT, B.S.

Great Britain

JOHN C. BRIDGE, F.R.C.S. (E.), D.P.H.
SIR KENNETH GOADBY, K.B.E., M.R.C.S., D.P.H.
SIR LEONARD HILL, M.B., F.R.S.
T. LISTER LLEWELLYN, B.S., M.D., M.I.M.E.
SIR THOMAS OLIVER, M.D.
R. PROSSER WHITE, M.D., M.R.C.S.
H. M. VERNON, A.M., M.D.
D. A. COLES, M.D.

South Africa

E. H. CLUVER, A.M., M.D., B.Ch., D.P.H.

Canada

J. J. R. MACLEOD, M.B.

Australia

CHARLES BADHAM, M.B., B.Sc., D.P.H.

MANAGING EDITORS

CECIL K. DRINKER, M.D.
PHILIP DRINKER, B.S., Ch.E.
MARION C. SHORLEY

THE JOURNAL OF INDUSTRIAL HYGIENE

VOLUME XIV FEBRUARY, 1932 NUMBER 2

THE BALTIMORE GAS APPLIANCE ORDINANCE AND ITS RELATION TO PUBLIC HEALTH*

WILMER H. SCHULZE

Chief, Division of Chemical Technology, City of Baltimore Health Department

HISTORICAL

THE danger to life and health attending the use of improperly designed and improperly constructed gas appliances is becoming increasingly recognized by health authorities. While the correctly designed and correctly constructed gas appliances when properly installed can be considered safe, it is the defective appliances which, by their production of carbon monoxide, have attracted the attention of health officials. In order to combat this insidious poisoning from carbon monoxide produced by defective appliances or leaky tubing, several cities have passed ordinances for the protection of the public. A brief review of these ordinances is here given in chronologic order.

Newark, N. J., was the first city to take cognizance of the danger attending the use of defective gas tubing, and in March, 1917, passed an ordinance "Prohibiting the Sale and Use of Other than Approved Tubular Connections for Illuminating Gas Fixtures and Appliances." This ordinance provides that only such tubing as has been approved by the Inspector of Gas and Gas Meters of the city of Newark shall be lawful for sale or installation. The ordinance is enforced by the Board of Health, the Assistant Superintendents of Buildings, the Police Officers, the Bureau of Combustibles and Fire Risks, and the Inspector of Gas and Gas Meters (1). The actual inspections are made by the Bureau of Lighting. Regulations have been promulgated to control the quality and registration of all tubing, and safety tests have been compiled. In rooming houses, where gas is frequently supplied to each room, inspections are made for defective tubing. While it is difficult to draw any definite conclusions as to the

* Received for publication Oct. 16, 1931.

beneficial results of the ordinance, accidental deaths attributed to the use of illuminating gas showed a marked decrease from 1920 to 1923. Solicitation of the co-operation of dealers, tubing manufacturers, and the Public Service Gas Company of New Jersey has resulted in providing the people of Newark with gas tubing of approved quality, and has served to warn the public of the possible danger in the use of gas tubing of doubtful quality.

Baltimore, Md., adopted a gas appliance ordinance in July, 1925. This ordinance, designed to control the sale and installation of all types of domestic gas appliances and gas tubing, was the first of its kind to be adopted in the United States. The need for such legislation was made apparent after an extensive investigation, by the Baltimore City Health Department, of the increasing number of fatalities attributed to the use of defective gas appliances (2). The United States Bureau of Standards, the United States Public Health Service, the United States Bureau of Mines, and the Consolidated Gas, Electric Light and Power Company of Baltimore gave valuable assistance in making the investigation possible. This investigation was conclusive. Detailed tests were made on appliances for the production of carbon monoxide under conditions simulating those existing at the time of accidents; blood tests were also made on the victims by means of the pyrotannic acid method of Sayers and Yant (3), in order to determine the degree of saturation of the hemoglobin by carbon monoxide. This test was also frequently used for determining the concentration of carbon monoxide in rooms where asphyxiations had occurred from the use of defective appliances. These studies indicated that a number of accidents were attributable to "raw" gas resulting from leaks, from poor or careless adjustment of appliances, or from old and inadequate appliances. In the majority of instances, asphyxiation was due to the formation of carbon monoxide in improperly designed equipment, or in old equipment which was out of adjustment or had been altered in some way. Studies of the chemical composition of the manufactured gas as supplied in Baltimore, its physical characteristics, and the conditions under which it was supplied to the consumers indicated that the hazard was not and is not peculiar to Baltimore.

Los Angeles, Calif., experienced during December, 1924, and the early part of the following January a large number of asphyxiations attributable to defective appliances (4). A committee was appointed by the mayor to investigate the cause of these poisonings, and a technical subcommittee was appointed to make tests of such gas appliances as were in general use in Los Angeles. This subcommittee followed the procedures used in previous investigations by the United States Bureau of Standards, the United States Bureau of Mines, and the Baltimore City Health Department. Of a total of twenty-eight fatal poisonings, nineteen were attributed to appliance operation; of fourteen nonfatal cases, all were due to faulty performance of appliances. Owing to the general use of space heaters in Los Angeles, tests

were confined to this type of appliance. Out of twenty-eight appliances tested seven, or 25 per cent., produced carbon monoxide during open room tests. The percentages of carbon monoxide formed varied from 0.02 to 3.8. As a result of this extensive investigation a proposed gas ordinance, simulating the Baltimore ordinance, was compiled. However, instead of adopting this ordinance, designed to control the sale and installation of all types of domestic gas burning appliances, Los Angeles adopted an amendment to its building code providing only for control through approval of gas fired, warm air furnaces. Since 1927 Los Angeles has been enforcing an ordinance governing the installation of this type of appliance. The amendment requires that gas furnaces conform to certain construction and performance specifications which in general are identical with those adopted by the American Gas Association.

New York City adopted an ordinance in August, 1926, prohibiting the sale of any but approved flexible gas tubing. This tubing must meet the requirements of the American Gas Association.

Hartford, Conn., in April, 1927, added provisions to its building code requiring the licensing of gas appliance dealers and the registration of all gas appliances sold. It also provided that all appliances should bear the seal of approval of the American Gas Association Testing Laboratory.

The city of Berkeley, Calif., adopted a gas ordinance in October, 1927, providing that every appliance offered for sale, exposed for sale, or installed in the city of Berkeley shall be of a design and construction approved as to safety by the American Gas Association Testing Laboratory.

Pasadena, Calif., adopted an ordinance in March, 1928, governing the approval of gas burning, warm air furnaces. This ordinance consists largely of installation and construction requirements, and accepts appliances of this type that are approved by the American Gas Association.

While other cities have under consideration ordinances designed to control the sale and installation of gas burning appliances, Baltimore was the first city in the United States to put into effect an ordinance of this character (5). By means of this ordinance many questionable and improperly designed gas appliances have been eliminated from sale in this city, thus affording the citizens protection from possible illness, prostration, and death from carbon monoxide poisoning.

Relation of Carbon Monoxide Poisoning to Public Health

Carbon monoxide is probably responsible for more fatalities than any other poisonous gas. Since it is colorless and odorless, and hence gives no warning of its presence, it is also the cause of numerous nonfatal asphyxiations.

In domestic life there are several sources of carbon monoxide, produced in concentrations sufficient to cause asphyxiation. The running of automobile engines in closed private garages will rapidly vitiate the atmosphere to such an extent that death will very quickly ensue. The use of improperly designed or improperly adjusted gas burning appliances in

poorly ventilated rooms frequently results in asphyxiation. Coal fired stoves and furnaces, unless they are adequately ventilated to the outside, may emit sufficient carbon monoxide to cause fatal poisoning. Asphyxiations from carbon monoxide from the above-mentioned sources are numerous during the winter months, as is evidenced by vital statistics and by the accounts published in the daily press.

Exposure to carbon monoxide in varying concentrations is encountered by workers in a number of industrial trades. Dr. Alice Hamilton (6) states that the following are thought to be most in danger:

Laundry workers, especially ironers.
Pressers in tailor shops.
Furnace tenders.
Gas workers, especially men making connections and reading meters.
Painters working in rooms in which salamanders are kept burning to dry the walls.
Printers, especially linotypists.
Molders of metal where gas is used for heat.
Men working in canneries on soldering machines.
Miners, especially in mines where blasting is done continuously.
Garage workers, especially repairers.

Poisoning as a result of exposure to carbon monoxide may be divided into two types, acute and chronic. The former is more apparent to health officials and the general public owing to the relative ease of detection. The victim either is entirely unconscious or is in a state of mental confusion; respiration consists of gasps; nausea and vomiting may occur; the face may be cyanotic or the cheeks may be very rosy. This condition is usually preceded by other symptoms, such as tightness across the forehead, pressure and throbbing in the head, weakness in the knees, dizziness, mental confusion, and nausea. Unconsciousness may occur quickly, without the appearance of the intermediate symptoms and before the person affected realizes his predicament.

Chronic carbon monoxide poisoning resulting from exposure to low concentrations of the gas over long periods of time, is not so readily diagnosed. The symptoms usually given are of a general character and bear a similarity to symptoms of other common disorders. The patient may complain of headaches, dizziness, lassitude, general muscular weakness, loss of appetite, nausea, or shortness of breath on exertion. While these symptoms are similar to a progressive acute poisoning, they are usually attributed to some cause other than carbon monoxide. Apparently some persons can become accustomed to long exposure to low concentrations of the gas without suffering serious injury, while others become permanently affected. The injury may be exhibited as muscular weakness of the heart, anemia, partial or complete loss of vision or power of speech, or in some other nervous manifestation.

Acute Poisoning

Acute carbon monoxide poisoning varies in severity with the concentration of carbon monoxide inhaled and the duration of exposure. The tissues of the body depend upon the hemoglobin of the blood for the transportation of oxygen supplied by the inspired air. Without this constant supply of oxygen the body tissues

are damaged, and if this condition is prolonged for sufficient time, death ensues. Carbon monoxide also combines with the hemoglobin of the blood, having an affinity for this compound which is approximately 300 times greater than that of oxygen. As a result of this greater combining power, carbon monoxide displaces the oxygen of the blood. The rapidity of this exchange of carbon monoxide for oxygen depends upon the length of exposure and the concentration of carbon monoxide in the inhaled air. Henderson and Haggard (7) give the following table as a measure of the physiologic effect when the time of exposure is measured in hours and the concentration of carbon monoxide is expressed in parts per million:

Time × concentration = 300, no perceptible effect.
Time × concentration = 600, a just appreciable effect.
Time × concentration = 900, headache and nausea.
Time × concentration = 1,500, dangerous.

For example, exposure to an atmosphere containing 3,000 parts per million of carbon monoxide, or 0.3 per cent., for half an hour would be dangerous: 3,000 × 0.5 = 1,500.

As the hemoglobin of the blood combines with the carbon monoxide of the inspired air, the oxygen of the blood is gradually displaced; the degree of saturation of the blood with carbon monoxide depends upon the concentration of carbon monoxide and the duration of exposure. As the blood saturation increases, the physiologic effects become more alarming (7). A saturation of 20 per cent. may produce slight headache; 30 per cent. decided headache and irritableness; 40 to 50 per cent. headache, confusion, and collapse on exertion; and 60 to 70 per cent. unconsciousness. A saturation of 80 per cent. is rapidly fatal; over 80 per cent. is immediately fatal.

Removal of the victim of acute carbon monoxide poisoning to a source of fresh air is imperative since the oxygen of the air, free from carbon monoxide, will begin immediate displacement of the carbon monoxide which has combined with the blood. The patient's heart is weak from endeavoring to compensate for the loss of oxygen; hence considerable care is necessary to prevent exertion, and stimulants should be avoided.

Replacement of the carbon monoxide in the blood is hastened by inhalation of a mixture of 5 per cent. carbon dioxide and 95 per cent. oxygen (7). This method of resuscitation is now in use in most large municipalities and has no doubt saved the lives of many victims of acute carbon monoxide poisoning. Recent investigations (8) indicate that a mixture of 7 per cent. carbon dioxide and 93 per cent. oxygen may be even more efficacious than the 5 per cent. mixture.

Chronic Poisoning

While persons apparently recover quite rapidly from acute carbon monoxide poisoning, this is not the case with exposure to low concentrations over long periods of time. It is this phase of poisoning, commonly termed chronic carbon monoxide poisoning, which should engage the attention of public health officials. The use of defective or improperly adjusted gas burning appliances in homes presents a possibility of many unknown cases

of ill health due to the effects of low concentrations of carbon monoxide inhaled over long periods of time.

The following excerpts from the current literature on carbon monoxide poisoning will indicate some of the physiologic effects to be anticipated from prolonged exposure to low concentrations of carbon monoxide.

Henderson and Haggard (7) point out the similarity of the effects of small doses of carbon monoxide to those resulting from deprivation of oxygen as, for example, in persons moving to high altitudes. Two types of response are noted. One results in an increase in the number of red cells in the blood in order to compensate for the oxygen deprivation due to the combination of the carbon monoxide with the hemoglobin. This condition is noticed in workers about blast furnaces and in some automobile repair shops. When the periods of exposure are irregular or relatively brief, the other type of response results. (This type of exposure simulates what would occur in houses using defective or improperly adjusted gas burning appliances.) The mechanism of compensation is alternately started and reversed. As a result there is evidence of nervousness, irritability, and weakness similar to "air staleness" of aviators making repeated flights to great altitudes.

The Bureau of Industrial Hygiene of the New York State Department of Labor (9), in a preliminary report on carbon monoxide poisoning due to intermittent exposure to small concentrations over long periods of time, gives the following typical symptoms after examining twenty men regularly employed in service stations: intense headache of long duration, ashen pallor, nausea, and nervous irritability.

Slot (10) states that the effects of exposure to small amounts of carbon monoxide are probably neurotic and are associated with headache, irritability, emotional disturbances, and fatigue.

Alice Hamilton (6) states that the great difficulty in detecting this type of poisoning is that the symptoms are rarely characteristic. Usually there is only complaint of headache, palpitation of the heart, breathlessness, general nervousness, and disturbed sleep.

Beck and Fort (11), in a study of a number of cases of probable exposure to low concentrations of carbon monoxide over long periods of time, give the following usual symptoms: headache, either frontal or temporal; dizziness; later tingling in the legs which develops into a general paresthesia accompanied by palpitation, insomnia, mental retardation, and a feeling of general exhaustion. There is progressive muscular weakness and incoordination of movements, even affecting the speech. Pallor with a variable blood picture is frequently observed. They warn against diagnosing as chronic carbon monoxide poisoning cases without a history of exposure to atmosphere containing carbon monoxide.

Sayers, Yant, Levy, and Fulton (12) subjected a number of men to atmospheres containing 2, 3, and 4 parts of carbon monoxide per 10,000 parts of air. These exposures were made daily for from four to seven hours over a period of two months. When the blood saturation reached 30 to 35 per cent. there was evidence of tightness across the forehead, lassitude

and drowsiness, slight headache, and distinct frontal headache; in a few cases there were occipital headaches, vertigo, weakness, and nausea. There was a distinct increase in hemoglobin in all cases but one, and a distinct increase in red blood cells in all cases except two. There was no indication that the experiments were deleterious to the health of the men.

The foregoing statements indicate the need of additional investigation in determining the deleterious effects on health resulting from prolonged exposures to small concentrations of carbon monoxide. Studies should be made of persons in houses where exposures may have continued over a period of years. Defective or improperly adjusted gas appliances may not produce sufficient carbon monoxide to cause acute poisoning, but they may produce enough to cause general ill health. Irritableness, headaches, vertigo, nausea, and general weakness are often common complaints resulting from these low concentrations of carbon monoxide and are frequently attributed to some other cause. Blood pictures of persons failing to compensate for oxygen deprivation simulate those of anemia. While the number of cases of acute poisoning may be low, little is known of the extent of chronic poisoning in homes where gas appliances are used. It is this type of poisoning affecting the general well-being of individuals that requires the attention of health officials.

Preliminary Studies of Gas Appliances in Baltimore

It is pertinent that some statement be made as to the entrance of the Baltimore City Health Department into the study of the production of carbon monoxide by defective or improperly adjusted gas appliances. The following incident which occurred during extremely cold weather in January, 1923, aroused the interest of the Department: A family of five—parents and three children, one an infant and the others 5 and 7 years of age—had, from all appearances, been exposed to high concentrations of carbon monoxide. The Health Department, investigating the case, ascertained that the family had purchased a new space heater and the necessary flexible tubing for connecting it to the piping. The whole family occupied one bedroom and the heater was installed in this room. Early in the evening the infant was put to bed and the heater was lighted to keep the room warm. After the lapse of an hour or two the infant was aroused and was found to be very much nauseated. It was brought into the living room with the other members of the family, and after several hours became apparently all right. Later the entire family retired, leaving the heater lighted and the windows closed. About 1 A.M. the father awoke, very much nauseated; on endeavoring to walk he became dizzy and fell, striking the heater. The noise apparently awakened the mother who in turn aroused the two children. The infant was apparently lifeless. All were very sick and nauseated. As soon as they were able, they sent for a doctor, who pronounced the infant dead. The remainder of the family recovered. An investigation made the next day by the Health Department revealed no leaks in the piping or tubing, and apparently the burner of the heater performed normally. No explanation

of the source of carbon monoxide was apparent. Conditions as they existed at the time of the accident were duplicated as closely as possible and tests were made for carbon monoxide. The results were positive.

This incident led to an investigation as to the source of the carbon monoxide, since no escape of "raw" gas was detectable. Tests indicated that the faulty design of the heater failed to admit a sufficient secondary supply of air to burn the gas completely, with the result that carbon monoxide was produced. Apparently the freely burning gas yielded a mixture of carbon monoxide and carbon dioxide instead of all carbon dioxide. Had complete combustion of the gas occurred, no carbon monoxide would have been produced and the accidental poisonings would not have happened. The improper performance of this gas appliance indicated the need for investigating the performance of gas appliances in general.

A comparison of the death rate attributed to accidental poisoning by illuminating gas for the year 1922 with the death rate for typhoid fever for the same year showed the former to be over twice the latter. These accidental deaths were attributable to two causes—escape of raw gas through ignorance or carelessness, and production of carbon monoxide as a result of faulty design of appliances. Flexible rubber tubing—cheaply made—was responsible for a large number of accidents. In several cases, leaky tubing which, either through ignorance or through carelessness, had been patched with various kinds of tape, rags, or gum permitted the escape of sufficient gas to cause asphyxiation. Frequently accidents were due to tubing which was so loose or so enlarged at the ends that a slight strain caused it to be dislodged. Gas cocks which could be very easily turned were also a frequent cause of accidental prostration.

The more insidious cause of accidental poisoning, namely, the production of carbon monoxide by improperly designed appliances, was for a time unexplainable. Assistance in this investigation was readily given by the United States Bureau of Mines, the Public Health Service, and the Bureau of Standards, and by the Consolidated Gas, Electric Light and Power Company of Baltimore.

In order to secure a complete record of all accidental poisonings attributed to illuminating gas, arrangement was made to have all such cases referred immediately to the Health Department. Extensive investigations were made of each accident reported. If the performance of an appliance was indicated as the cause, conditions as they existed at the time the accident occurred were duplicated as closely as possible and tests were made for the presence of carbon monoxide. In a number of instances, appliances which were found to be defective were removed to the laboratory for more thorough study.

During the investigation, eighteen cases of asphyxiation were studied which involved forty-eight persons who were partially asphyxiated and five who died. Three of the deaths occurred in persons who were sleeping in closed bedrooms while room heaters were in use. Tests made on these heaters revealed that large quantities of carbon monoxide were being pro-

duced. Of the appliances found to be producing carbon monoxide eight were water heaters, six room heaters, and five cooking stoves. The improper performance of these appliances was attributed to faulty design, to improper installation or adjustment, to deterioration or clogging of vital parts, and to carelessness or ignorance in their operation. The connection to flues of all appliances burning large quantities of gas, especially in poorly ventilated rooms, and the prohibition of the sale and installation of appliances not having a satisfactory range of safe operation would, it seemed, reduce to a large extent accidental asphyxiations from carbon monoxide.

A committee consisting of representatives of the Health Department, the United States Bureau of Mines, the United States Public Health Service, the American Gas Association, and others vitally interested was called upon to draft an ordinance based on the results of this investigation. This ordinance was designed to limit the sale and installation of all domestic gas tubing, appliances, and appurtenances to those meeting requirements based on the protection of the health and safety of the public. Specifications were adopted largely from those of the American Gas Association with the omission of those tests not having any direct relation to health and safety.

Baltimore Gas Appliance Ordinance

The outgrowth of the investigation under the direction of the Health Department was the passage of the gas appliance ordinance in July, 1925. The ordinance as originally drawn up required that tubing, appurtenances, and devices conform to the specifications of the American Gas Association or to the specifications promulgated by the Gas Reference Committee. These specifications became part of the rules and regulations of the Commissioner of Health. The limiting of specifications to those adopted by the American Gas Association or by the Gas Reference Committee, as well as the delegating of partial responsibility or authority for rules and regulations to the Gas Reference Committee, was contested and declared illegal. As a result, the ordinance was amended in May, 1927; as revised it delegated to the Commissioner of Health sole authority in adopting rules, regulations, and specifications, and permitted him to be technically advised by the Gas Reference Committee, and to consider the rules, regulations, and specifications established by the American Gas Association, or any other rules, regulations, and specifications relating to the subject.

The ordinance as amended was again contested, with the result that another amendment was added in April, 1928. The contention was made that discrimination was evidenced, in that the testing of appliances was limited to the laboratory of the American Gas Association. In order to meet this contention the Commissioner of Health was authorized to direct tests to be made by the laboratories of the United States Bureau of Standards, the Johns Hopkins University, or any other testing agency of which he approved.

The two amendments to the original ordinance were the result of litigation

on the part of a stove manufacturer who refused to have tested appliances which were on sale in the city. The constitutionality of the ordinance was contested in the lower courts, and the ordinance was declared legal. Recourse was had on the part of the manufacturer to the Court of Appeals. This court upheld the decision of the lower courts, thus placing the ordinance on a sound legal basis.

It will be of interest here to consider the provisions of the amended ordinance for the control of the sale and the installation of gas appliances.

All appliances, tubing, appurtenances, or devices designed to be used with manufactured gas must be registered with the Commissioner of Health before they are eligible for display, sale, or installation in the city of Baltimore. Registration of appliances requires that an application for registration be made and that a certificate from a testing laboratory be submitted. This certificate contains a complete description of the appliance, and serves as a means of identification for inspection purposes. Upon receipt of the application for registration and the certificate of test, the appliance is registered and a numbered certificate of registration is issued. Should any question arise as to the identity of any appliance with one as originally registered, recourse is had to the original certificate of test. This has served in several instances to establish the status of questionable appliances. By keeping on file duplicates of all certificates of registration issued, an accurate record of all appliances eligible for sale and for installation is readily accessible.

Dealers who sell or display for sale any tubing, appliances, appurtenances, or devices to be used in connection with manufactured gas are required to obtain a gas appliance dealer's license. This license is renewable annually and may be revoked or suspended by the Commissioner of Health because of violation of the ordinance, provided the dealer is first accorded a hearing. The licensing of dealers has been of material aid in inspecting appliances offered to the public. By having a complete register of all dealers it is a comparatively easy matter to acquaint them with new regulations or to furnish them with current lists of registered appliances.

Persons desiring to engage in the trade of gas fitting are required to pass a written and an oral examination to prove their capability. These examinations are given by a committee designated by the Commissioner of Health. Persons passing the tests are issued registration cards, and only those registered by the Commissioner of Health are eligible to practise the trade of gas fitting. If the work of a gas fitter is found to be faulty, his registration is liable to revocation by the Commissioner of Health. Thus the ordinance provides for the control of both the appliances installed and the manner of installation.

It is by means of these three provisions—namely, registration of appliances, licensing of all appliance dealers, and registration of all gas fitters—that the sale and the installation of appliances are limited to registered types.

The question naturally arises as to how those concerned with the sale and installation of gas appliances are to know the status of an appliance.

This is provided for in the ordinance which requires that a complete list of registered appliances be issued quarterly to all licensed dealers in gas appliances. This provision has been extended to include registered gas fitters. In order that newly registered appliances may be brought to the attention of gas dealers and gas fitters, supplementary lists are issued during each month between the quarterly issues. By this means dealers and fitters are kept informed of the appliances eligible for sale and for installation.

Specifications for the different types of appliances simulate those of the American Gas Association, with the omission of those requirements which have no bearing on the health and safety of the public. In order that the Commissioner of Health may be advised on technical questions pertaining to specifications for gas appliances, provision is made for the formation of a Gas Reference Committee. This committee consists of the Commissioner of Health and one representative from the following organizations: Public Service Commission of Maryland; Inspector of Buildings; the Consolidated Gas, Electric Light and Power Company of Baltimore City; Master Plumbers Association; Retail Gas Appliance Dealers Association of Baltimore; and the American Gas Association. Provision is made for the enlargement of this committee by election of another member from an organization representing the interests, respectively, of the public, the gas manufacturing industry, the gas appliance dealers, and plumbers and gas fitters. This committee has been of valuable assistance to the Commissioner of Health in compiling specifications and requirements for the various types of gas appliances, appurtenances, and devices.

It soon became apparent that in order to secure effective enforcement of the ordinance and to cope with certain unforeseen administrative problems, a series of regulations was needed to extend the scope of the ordinance. A set of regulations was therefore compiled and adopted by the Commissioner of Health in February, 1930.

The necessity for these regulations was apparent after making a survey of field conditions. Installation of unapproved appliances by registered gas fitters was a common occurrence, since no method of control of installation was enforced. Gas fitters were unfamiliar with the ordinance and were not informed as to which appliances were approved. To correct this condition, registered gas fitters were put on a mailing list to receive the published lists of approved appliances. They were instructed that after a certain date, it would be required of them to state in all applications for installation the identification of appliances to be installed, and these must be of approved type.

Used or second-hand appliances in all states of deterioration were being sold or attempts made to recondition them. Many of them were of obsolete designs and presented the possibility of production of carbon monoxide if put into service. These appliances are probably a much greater source of danger than new appliances. Provision was made in the regulations to include all used or second-hand appliances within the scope of the

ordinance. Several cases of acute poisoning indicated the need for this regulation.

While the ordinance prohibited the sale or installation of unregistered appliances, no procedure was included for the field enforcement of this provision. A regulation was therefore adopted providing for the attachment of a "Notice of Detention" to unregistered appliances and for issuing a letter of warning against the unauthorized removal of detained appliances.

The enforcement of these regulations has eliminated many second-hand appliances which were of questionable performance and has decreased the possibility of the installation of unregistered appliances, thus offering to the public better protection from possible poisoning due to improperly designed appliances.

Investigation of Accidental Poisoning

While comparatively few accidents now occur which can be attributed to improper performance of gas burning appliances, quite a number do take place as a result of leaks and of carelessness. Many persons not realizing the danger of interfering with the performance of appliances are prone to be careless. Such instances are in the placing of obstacles over the vents of water heaters, range ovens, or space heaters; in replacing baffles in water heaters where impingement of the flame results; in patching gas tubing with tape, gum, etc.; in placing solid tops on ranges designed for open grates; in increasing the height of burner flames so that impingement results, accompanied by the production of carbon monoxide.

In order to gain some knowledge as to the safety afforded in the use of registered appliances, arrangement has been made with the local Police Department, the Ambulance Service of the Fire Department, and the Consolidated Gas, Electric Light and Power Company to notify the Division of Chemical Technology of all accidental cases of acute "gas" poisoning as soon as possible. Investigations are made, and whenever the accident is attributed to the performance of an appliance, tests are made for the production of carbon monoxide. During the winter of 1929 to 1930 two such cases were traced to the improper performance of circulating tank water heaters, one of which resulted in death. Tests made on these heaters showed that large quantities of carbon monoxide were being produced. Both were second-hand appliances. In no instance has an accidental poisoning been attributable to the performance of a registered appliance.

The investigation of accidental poisoning connected with the performance of an appliance is of importance. Conditions as they existed at the time of the accident are duplicated as closely as possible, and samples of the products of combustion are collected from the appliance during operation. The appliance is permitted to burn for several hours and samples of the room atmosphere are collected from time to time. These samples are submitted to the laboratory to be examined quantitatively for carbon monoxide. Tests for carbon monoxide in the room atmosphere are also made at the scene of the accident, during the investigation, by means of the pyrotannic acid method of Sayers and Yant (3). When dangerous quantities

of carbon monoxide are produced, steps are at once taken to have the appliance discarded.

Study of Circulating Tank Water Heaters

During the winter of 1929 to 1930, several cases of acute carbon monoxide poisoning due to defective circulating tank or coil type water heaters occurred. These cases led to an investigation of water heaters, especially those of unregistered types. While this investigation is still in progress, the results thus far obtained are of interest. This type of water heater is seldom vented, consumes large quantities of gas, and is frequently installed in kitchens and at times in bathrooms. The water heaters tested were located in all sections of the city and had been installed for from one to twenty years. Of a total of eighty-nine heaters tested, eighteen were of registered types.

Our specifications for this type of appliance limit the production of carbon monoxide to 2 parts in 10,000 in the products of combustion escaping from the vent of the water heater. Of the eighty-nine heaters tested, sixty-four (71.9 per cent.) produced less than this amount of carbon monoxide; three (3.4 per cent.) produced between 26 and 50 parts per 10,000; two (2.2 per cent.) between 51 and 100 parts per 10,000, and the same number between 100 and 200 parts per 10,000. In no instance was a registered appliance responsible for the production of dangerous concentrations of carbon monoxide. All the appliances producing carbon monoxide were unregistered and were installed before the enactment of the ordinance.

Accumulation of deposits from corrosion on the burner of some of these appliances apparently affected the proper combustion of the gas. In several instances tests made before and after cleaning dirty burners showed a marked reduction in the concentration of carbon monoxide in the products of combustion.

In one instance a water heater installed in a kitchen was found to be producing a concentration of 170 parts per 10,000 of carbon monoxide. On closing the room tightly and permitting the heater to burn for one hour, the concentration of carbon monoxide in the room was found to have reached the dangerous amount of 25 parts per 10,000. Fortunately in this case the heater was installed in such a manner that the vent was close to a transom over the kitchen door leading to the outside. Under conditions of restricted ventilation acute poisoning might readily occur.

Fortunately the burning of the coil type hot water heater is usually limited to comparatively short periods of time, so that in case dangerous concentrations of carbon monoxide are emanating from the vent, sufficient time is not given to build up concentrations in the room which are capable of producing acute poisoning. Frequent exposures to the concentrations which do exist are no doubt, however, responsible for a number of cases of malaise. Over a long period of time this condition may become serious.

It is our intention to continue the study of the performance of older, untested appliances, including space heaters and gas ranges, and also to include for comparison tests made on registered appliances which have been in service for several years. If the

results of this study warrant it, they will be published at some future date.

It is through a study of this character that we may appraise conditions existing in homes where older, untested gas appliances are in use. Many persons are prone to continue the use of old appliances through ignorance of the possible inherent dangers in their use. Low concentrations of carbon monoxide from these appliances, over long periods of time, have no doubt a marked effect upon the health of many persons. In order to gain some information regarding the extent of these conditions it is our intention to extend our study to include various types of appliances.

American Gas Association Testing Laboratory

On June 1, 1925, the American Gas Association established a central testing laboratory in Cleveland, Ohio. This laboratory was founded to insure the user and the public in general safe gas appliances, to assist the appliance manufacturer in producing safe and efficient equipment, to improve the art of appliance design, and to eliminate from the market appliances that do not meet proper concepts of substantiality, durability, and safety (13). Tests of appliances are made in accordance with requirements prepared by committeemen representing gas companies, appliance manufacturers, the United States Bureau of Standards, the United States Bureau of Mines, the Canadian Gas Association, the United States Bureau of Home Economics, the United States Public Health Service, the American Home Economics Association, the Master Plumbers Association, and the Underwriters Laboratories.

Without doubt, the establishment of this laboratory has had a wide influence on the production of safe gas burning appliances, with a consequent beneficial effect on the general health of the public.

Discussion

Acute poisoning from carbon monoxide attributed to improperly designed or improperly adjusted gas appliances has been responsible for a number of deaths in communities where gas is used for fuel. While these cases are comparatively easily recognized by attending physicians and health officers, the diagnosis of the chronic form of poisoning is difficult. Investigations made in Baltimore indicate the possibility of many such cases resulting from exposure to low concentrations of this insidious gas over long periods of time from older, untested gas appliances. The similarity of symptoms resulting from these exposures to those of other minor ailments tends to obscure the potential public health danger of this grave malady, and recognition of this condition is not immediately apparent to the medical practitioner. The attending difficulties in recognizing the varied effects of this type of poisoning emphasize the potential danger to the public health at large. According to our investigations, a considerable portion of the public is exposed and will continue to be exposed to this danger as long as untested gas appliances are used. While the use of properly designed and properly adjusted gas appliances is safe, disastrous results often follow

the use of appliances which have not been put through a series of tests to prove their safety. It is to eliminate these appliances that the Baltimore ordinance was adopted. As a result of the adoption of the ordinance purchasers are now assured that gas appliances offered for sale have been put through rigid tests to prove their safety when properly installed. It is our belief that the replacement of the older, untested appliances by those which have been tested will have a marked effect in preventing ill health from exposure to low concentrations of carbon monoxide over long periods of time.

The duty of public health officials is to protect the health of citizens of the community to the utmost of their ability. The need of some control over the promiscuous use of defective gas appliances is apparent from the many reports of accidental poisonings due to carbon monoxide from this source. While the extent of exposure to low concentrations of this gas is an unknown quantity, it behooves officials to take recognition of the fact that these conditions can be largely, if not entirely, eliminated by requiring that types of gas appliances sold or installed within the community be first tested by a recognized testing agency to prove their safety.

Summary

1. The increase in the use of gas as fuel attended with the increase in the number of different types of gas burning appliances, with the possibility of the production of carbon monoxide owing to defective construction or improper installation, is connected directly with the general health of the public.

2. Public health officials in several cities have taken cognizance of this possible health hazard from the utilization of gas in homes and, as a result, ordinances have been passed or are under consideration to control the sale and installation of gas appliances.

3. From investigations it is evident that many persons are exposed to varying quantities of carbon monoxide and as a result suffer from illness difficult to identify and of an insidious character. Similarity of the symptoms to those in other minor ailments confuses correct diagnosis of many of these cases.

4. A study of a number of untested, circulating tank water heaters indicates that this type of appliance may produce concentrations of carbon monoxide which are dangerous to health.

5. It is our intention to extend the investigations of untested appliances to include other types of appliances, to the end of adopting additional requirements as to venting and installation.

Acknowledgment is here made of the valuable assistance and constructive criticism given by Mr. R. S. Craig, Director of the Bureau of Chemistry and Food, Baltimore City Health Department, and by Mr. R. M. Conner, Director of the American Gas Association Testing Laboratory, Cleveland, Ohio.

BIBLIOGRAPHY

1. Jennings, J. R.: Gas Age-Record, Oct. 27, 1923.
2. Shrader, J. H., and Mitchell, C. W.: Investigation of the Hazards from the Use of Manufactured Gas in Baltimore. Am. Jour. Pub. Health, 1924, *14*, 316.
3. Sayers, R. R., and Yant, W. P.: The

Tannic Acid Method for Quantitative Determination of Carbon Monoxide in the Blood. U. S. Pub. Health Rep., 1922, *37*, 2433.

4. Report of Technical Subcommittee to the Mayor's Committee on the Investigation of Gas Poisoning and Asphyxiations Resulting from the Use of Gas Heating Appliances in Los Angeles and Vicinity, Jan. 4, 1926.
5. Conner, R. M.: The Growth of Gas Appliance Ordinances. Pub. Utilities Rep., Oct., 1928.
6. Hamilton, A.: Carbon-Monoxide Poisoning. U. S. Bur. Labor Statistics, Bull. No. 291, 1921.
7. Henderson, Y., and Haggard, H. W.: Noxious Gases and the Principles of Respiration Influencing their Action. Am. Chem. Soc. Monograph Series, No. 35. New York, The Chemical Catalog Co., Inc., 1927.
8. Drinker, C. K., and Shaughnessy, T. J.: The Use of 7 Per Cent. Carbon Dioxide and 93 Per Cent. Oxygen in the Treatment of Carbon Monoxide Poisoning. This Jour., 1929, *11*, 301.
9. Mayers, M. R.: Carbon Monoxide Poisoning in Industry. Am. Jour. Pub. Health, 1927, *17*, 108.
10. Slot, G.: Chronic Carbon Monoxide Poisoning. Lancet, 1929, *1*, 635.
11. Beck, H. G., and Fort, W.: Chronic Carbon Monoxide Poisoning. Its Effect upon the Blood with Report of Two Cases Simulating Pernicious Anemia. Ann. Clin. Med., 1924–1925, *3*, 437.
12. Sayers, R. R., Yant, W. P., Levy, E., and Fulton, W. B.: Effect of Repeated Daily Exposure of Several Hours to Small Amounts of Automobile Exhaust Gas. U. S. Pub. Health Bull. No. 186, 1929.
13. Conner, R. M., and Vandaveer, F. E.: Testing Laboratory of the American Gas Association. Its Purposes and Accomplishments. Indust. and Engin. Chem., 1928, *20*, 307.

A PRESSURE CHAMBER INSTALLATION FOR STUDYING THE PHYSIOLOGIC EFFECTS OF PRESSURES VARYING FROM SIX TO SIXTY POUNDS PER SQUARE INCH ABSOLUTE*

R. M. Thomson, C. P. Yaglou, and A. B. Van Woert

From the Departments of Physiology and Industrial Hygiene, Harvard School of Public Health, Boston, Mass.

Introduction

THIS paper describes the engineering features of an experimental pressure chamber recently designed by and installed at the Harvard School of Public Health for the purpose of studying under accurately controlled conditions of temperature, humidity, and air movement, the physiologic effects of various pressures, ranging from 6 to 60 pounds per square inch absolute.

General Description of Equipment

The installation consists of a pressure chamber approximately 31 feet in length by 8 feet in internal diameter, which has two end compartments and an entrance and exit lock. Air is supplied to the chamber by either one or two air compressors; it first passes through an aftercooler, where it is cooled, and then flows into a receiver which equalizes the pulsations of the compressors and removes oil and excess moisture. It is next passed through an air conditioning apparatus, where it is brought to the desired dew point temperature, and then over heaters, in order to give a definite wet and dry bulb temperature in the compartments. To regulate the volume flow, the air is passed through uniform flow valves and through silencers before it enters the compartments. Inside each compartment, the air diffused at the top passes out at the bottom, then through pressure regulating valves and exhaust silencers, and finally through orifices, where the flow of air from each compartment is measured.

This equipment is installed in the basement of the School, now occupied by the Department of Industrial Hygiene. One large room approximately 23 feet, 9 inches by 19 feet, 6 inches is used for the auxiliary apparatus, and has been called the engine room. This room has been furnished with a desk, a small microscope bench, and a laboratory table which is equipped with a sink, water, gas, and electricity.

For the housing of the chamber itself, a new concrete building, 35 feet long, 14 feet wide, and 8 feet above grade, was erected at the back of the School, adjacent to the engine room. Part of the outside wall of the School forms one wall of the new building. The floor, which is of concrete, is 3 feet below the floor level of the basement of the School. Four piers of

* Publication No. 1 from the Miriam Smith Rand Fund. Received for publication Oct. 14, 1931.

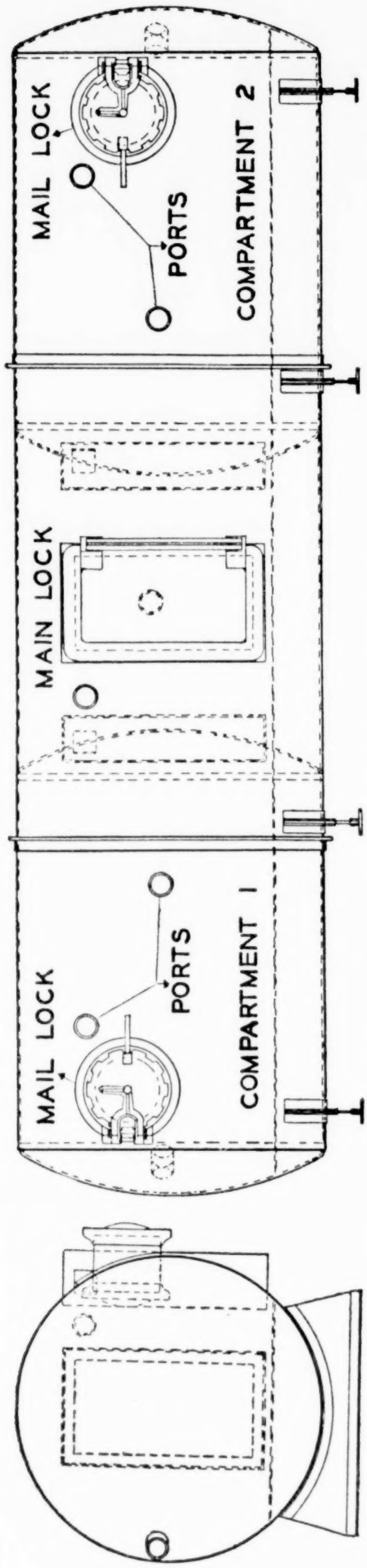

FIG. 1.—Front and end views of pressure chamber.

concrete are built up from the floor to support the chamber. There is a door at each end of the building, located as near as possible to the School building and on a level with the basement floor. Natural lighting is obtained through skylights.

DETAILED DESCRIPTION AND SPECIFICATIONS OF APPARATUS

Pressure Chamber[1]

Figure 1 gives a general idea of the chamber as a whole. It is a cylindrical tank consisting of two main compartments connected by an entrance and exit lock, which hereafter is referred to as the main lock. Two small locks are attached to the sides of each compartment and circular windows are inserted for each compartment and lock. The main portion of the steel shell is 8 feet in internal diameter, 29 feet, 1 inch in length, and one-half inch in thickness, with three longitudinal, electric arc butt-welded seams. The exterior chamber heads at each end are spherical segmental shells three-quarters of an inch in thickness, concave toward the main compartments, with cylindrical bases fitting within and welded to the ends of the main shell, making the over-all length of the chamber 31 feet, 6 inches.

The main lock is located in the center of the shell and is separated from the two main compartments by interior heads, which are welded to the main shell and are convex toward the main lock. These heads are similar to the exterior heads at the extreme ends of the chamber, except that they have framed door openings, centered on the

[1] This chamber was built by The Biggs Boiler Works Company, Akron, Ohio.

vertical axis of the tank, 2 feet, 6 inches above, and 2 feet, 3 inches below the horizontal axis. Another door opening, communicating with the outside, was made on the front of the main lock. These door openings are 2 feet, 6 inches wide, and 4 feet, 9 inches high in the clear. They are constructed of channel iron frames welded together and machined on both faces. Each is fitted with two cast steel doors swung on heavy roller bearing hinges of the wishbone type, so constructed that the door, when closed, will seal by means of a rubber gasket 1 inch by 1 inch, fitted to a groove in the door and projecting from the door face.

The two small locks for the transmission of material to and from the interior of each compartment when the chamber is in operation are conveniently located near the ends of the shell. These locks, with their centers 14 inches above the center line of the chamber, have an inside diameter of 20 inches and an inside length of 18 inches. There are two doors to each lock, one inside the compartment and the other outside. These doors can be closed against a gasket, and can be locked quickly and easily by revolving them approximately 4 inches.

Twelve port lights of 1-inch glass, having a diameter of $5\frac{1}{2}$ inches in the clear, are welded into the shell and into the heads so that a clear view is obtained from the outside into each compartment and the main lock, and from the main lock into each compartment. All windows are on a vertical plane, and each has a cover plate with latch hinged on the inside. A perforated metal disk is fitted on the outer side of each window to prevent the glass from scattering in case it breaks under high pressure. The metal perforations are large enough to leave the view unobstructed.

In order to provide a level surface in the compartments and the main lock, a floor of quarter-inch flat plates was built at a height of 1 foot, 3 inches above the tank invert. These plates are supported by I beams placed transversely on the chamber, approximately 3 feet apart.

The chamber is supported by four structural steel saddles mounted on concrete piers. In order to increase the rigidity and to prevent vibrations within the chamber, two continuous circumferential angles are welded around the shell, close to the middle saddles. The height of the concrete piers was so determined that the door in the entrance and exit lock could be entered from a floor on a level with the engine room.

All openings in the shell and heads for servicing the chamber are pipe couplings welded in place. The chamber is provided with water, drainage, electricity, and telephones. Check valves prevent loss of pressure should water fail, or should the pressure exceed water pressure. Drainage flows to a small tank under the chamber where suitable valves lead to an opening for connecting with the sewer without loss of pressure. All wires for electric and telephone service are led from junction boxes on the outside, which are threaded into service openings on the chamber, junction boxes and openings then being filled with a litharge and glycerin cement. Two independent circuits supply electricity for lighting the chamber, one of which is from the regular lighting system and

the other from the main switchboard of the School. Each compartment has two fixtures and the main lock has one. These are of the ceiling dish type and carry two 50-watt lamps, each circuit lighting one bulb in each fixture. All lights are controlled from the outside.

Channel iron pieces cut to fit the curvature of the shell are welded inside the chamber for the accommodation of shelves, laboratory benches, beds, and the like.

Dry and wet resistance thermometer bulbs are attached to the shell at appropriate points in the compartments, to give a continuous record of temperature conditions on a chart located in the engine room.

Cork insulation 2 inches thick with one-half inch of asbestos cement is applied to the outer surface of the shell, to the two interior heads on the convex side toward the lock, and to the two doors closing on the concave side of the interior heads. This provides complete insulation around each compartment.

Each compartment, as well as the main lock, is fitted with pressure gauges and a safety valve.

Conditions Governing Choice of Equipment

The ability to control the physical conditions of the air entering the chamber was deemed of major importance for the physiologic experiments that are to be conducted. The specifications for the construction of the chamber provide for a maximum pressure of 60 pounds per square inch absolute, and a minimum pressure of 6 pounds. With the atmospheric pressure at 14.7 pounds per square inch, and the internal pressure of the chamber at a maximum, the internal pressure would exceed the external by 60 pounds minus 14.7, or 45.3 pounds per square inch. On the other hand, if the internal pressure were at a minimum, it would be exceeded by the external pressure by 14.7 pounds minus 6, or 8.7 pounds per square inch; this would result in a partial vacuum within the chamber.

Within these ranges of pressure conditions, it was considered necessary to maintain any temperature from a minimum of 40°F. to a maximum of 120°F., with a maximum dew point of 100°F., and to maintain adequate continuous ventilation. Other conditions to be considered were the efficient, dependable operation of all equipment at all times without expert supervision, the adaptability of the equipment to changing experimental conditions and to the present service, and space available.

Air Compressors

Two horizontal straight line compressors are installed which have a combined free air capacity of approximately 300 cubic feet per minute. The compressors, of enclosed dust proof construction, are simple in design, require a minimum of space, and are belt driven by electric motors. Main bearings are lubricated by the splash system, and cylinders by force feed. Both machines are equipped with intake air unloaders. The compressors are so arranged that they can be run for pressure or for vacuum, individually or in parallel, by simply opening or closing by-passing valves. (See Fig. 2.) Although the compressors are not so efficient as vacuum pumps, they are suitable for maintain-

ing pressures less than atmospheric when the required capacity falls within the rating of the compressor. The advantages of such an arrangement are that it insures flexibility of the equipment under constantly changing experimental conditions, and that it requires a minimum of piping and floor space.

In order to eliminate vibrations in the School building, the foundations for these machines have been built up from a footing below the sub-basement floor, and have been brought up en-

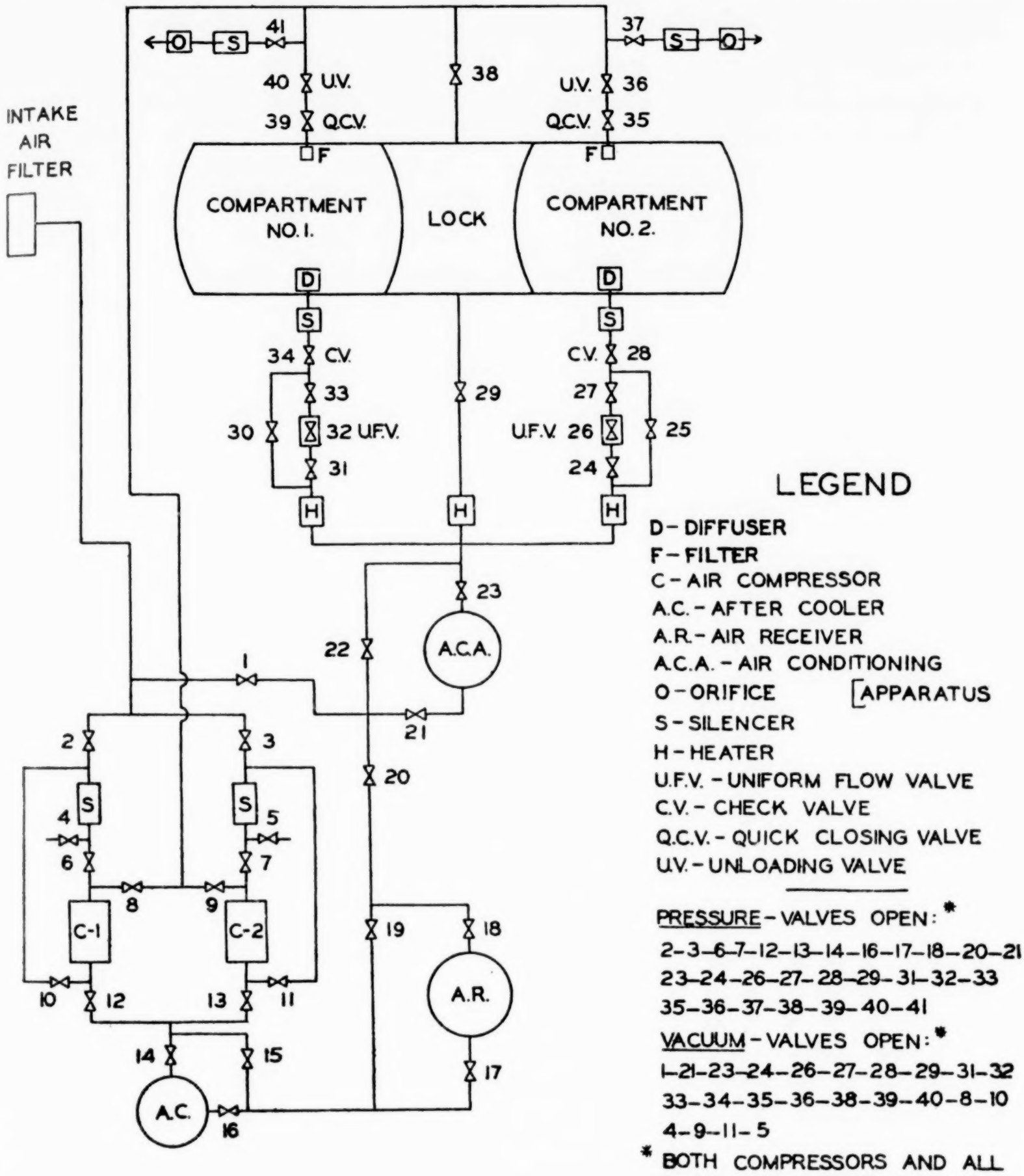

FIG. 2.—Diagrammatic sketch of main air line connections of pressure chamber.

tirely independent of the building structure. The power circuits for the compressor motors run direct from the main switchboard of the School.

Aftercooler

An aftercooler of the vertical type is installed on the discharge line close to the compressors. The aftercooler consists of a helical iron pipe coil within a welded steel shell. For cooling purposes, the coil is entirely surrounded by circulating water. After compression, the air passes through this pipe coil. In addition to cooling the compressed air to a point where most of the moisture and oil condense and can be removed, the aftercooler also gives a means of varying the temperature of the air before it passes through the air conditioning apparatus. For abnormally high and low temperatures, which may sometimes prevail in the pressure chamber, this arrangement is desirable.

Receiver[2]

An air receiver is installed between the aftercooler and the air conditioning apparatus for the purpose of equalizing discharge pulsations from the compressors, so that a steady flow of air can be delivered to the pipe line and the compartments.

The receiver is equipped at its lowest point with a suitable drain for drawing off accumulated water, oil, and impurities.

Air Conditioning Apparatus and Heaters

The purpose of the air conditioning apparatus is to control the dew point temperature of the air in the compartments. Figure 3 shows the air conditioning apparatus. Air from the receiver or from out of doors enters the conditioning apparatus at the lower left of the cylindrical shell. Inside this shell it is diffused upward evenly by means of a perforated pipe ring. It then passes over the cooling coils and comes in contact with a spray of water dripping over the coils. A closed metal cylinder fills the central space of the coil, thus diverting all the air over the cooling coils. Above the coils is the spray chamber proper. Here the air comes in contact with a finely atomized spray of water emerging under pressure from spray nozzles. These nozzles are attached to a pipe ring similar to that through which the air diffuses. After passing these spray nozzles and becoming fully saturated, the air flows through baffles which stop by impingement any entrained water that may be carried along. The air thus conditioned leaves the apparatus at the top of the shell, and passes over wet and dry resistance thermometer bulbs that are placed in the pipe line directly over the shell. The temperature of these bulbs represents the dew point temperature of the air, and it is recorded continuously on a chart in the engine room.

The dew point, or moisture content, of the air is controlled by the automatic regulation of the temperature of the spray water. To humidify the air, the spray water is heated in a pipe line heater on the external pump circuit; to dehumidify and cool it, the water is brought into contact with coils through which brine flows. This whole apparatus is insulated with 3 inches of heat insulating material.

[2] The compressors, aftercooler, and receiver were supplied by Ingersoll-Rand Company of New England, Boston, Mass.

In order to insure a definite dry and wet bulb temperature in the pressure chamber, the air leaves the air conditioning apparatus at a predetermined dew point temperature, and then passes through steam heaters (Fig. 2) before flowing into the chamber. There are three heaters, one for each compartment and one for the main lock. These are placed horizontally in the pipe line and have a cast iron outer shell with inner tubes $\frac{5}{8}$ inch in outside diameter, made of number 18 gauge admiralty metal. The free

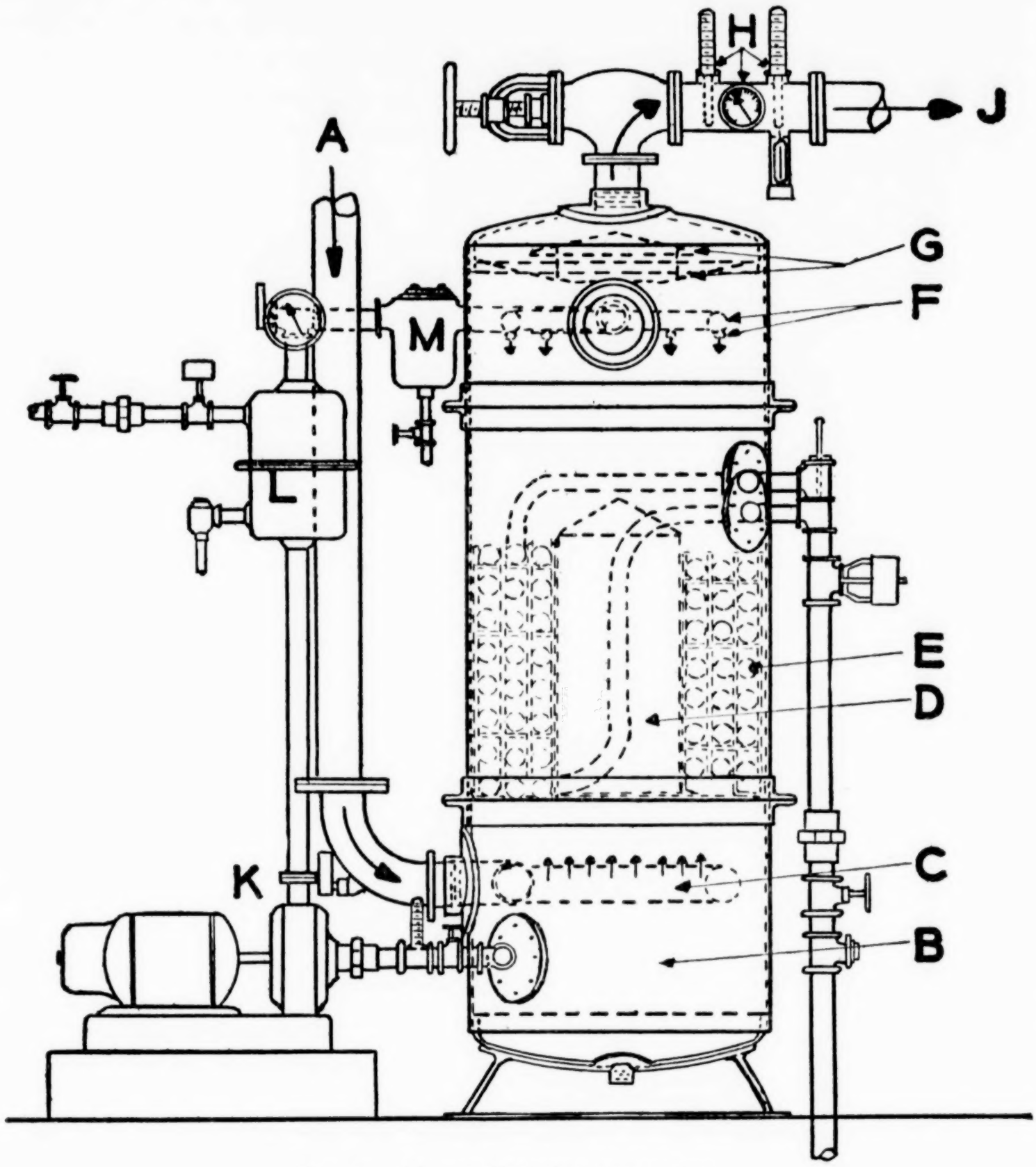

FIG. 3.—Air conditioning apparatus.

A = air from receiver or out of doors. B = water chamber. C = perforated pipe ring. D = space filler. E = brine coils. F = spray header and nozzles. G = baffles. H = wet and dry thermometers and pressure gauge. J = air to heaters. K = motor and pump for spray water. L = spray water heater. M = dirt strainer.

cross-sectional area of these tubes is 9.15 square inches. Steam is supplied to the inside of the shell around the outside of the tubes. In order to avoid fluctuations in temperature, the steam supply flows through a line equipped for orifices of various sizes or through a line equipped with valves, the combination used being determined by the temperature maintained in the pressure chamber.

The compartment heaters are controlled by thermostatic valves of the aerofin bulb type. In addition, each compartment has a coil heater in the diffusing chamber (Fig. 2). These heaters are under the same thermostatic control as the compartment heaters and are used for maintaining abnormally high temperatures. The temperature of the main lock during decompression to atmospheric pressure and from atmospheric to pressures less than atmospheric is maintained by an aerofin radiator which is also under thermostatic control.

Ventilation and Pressure Control[3]

The maintenance of a continuous ventilating current of air at a constant pressure, to one or both compartments, is a prerequisite. Two valves for each compartment are provided to take care automatically of this condition. Figure 2 shows the relative positions of these valves. Nos. 26 and 32 are uniform flow valves regulating the flow of air before it enters a compartment; Nos. 36 and 40 are unloading valves on the exhaust side of the compartment regulating the pressure. These valves are of the balanced lever type, and in addition, Nos. 26 and 32 are provided with a hand operated lever by means of which the valve orifice opening can be adjusted so that the same constant flow of air may be maintained during stage decompression of the compartments. The diaphragms of all four valves are on the chamber side.

The flow of air through a compartment is measured by means of orifices with curved inner edges open to the atmosphere. These are placed on the exhaust side of the compartment, after the silencer, and at the end of a 10-foot length of straight sheet-metal pipe 5 inches in diameter. A manometer connected to the nozzles is calibrated to give air flow reading directly in cubic feet per minute.

Main Air Intake, Auxiliary Piping, and Accessories

The main air intake to the compressors is located outside the building and is so placed that the temperature of the incoming air will be comparatively low at any time throughout the year. Attached to the intake is an air filter of the oil coated type, from which a 6-inch galvanized iron pipe runs to the branch connection for the compressors. Figure 2 shows a 3-inch galvanized iron pipe running from the branch connection to the intake of the compressors, and continuing on from the discharge side through to the pressure chamber. Three inches is the full diameter of the intake and discharge openings on the air cylinders of the compressors.

If the compressors are used as vacuum pumps, and if they are to be utilized to the fullest extent, it is necessary to use a series of valves in

[3] Uniform flow and pressure control valves were supplied by Ruggles-Klingemann Manufacturing Company, Salem, Mass.

the pipe line around the intake and discharge sides of each compressor. The direction of air flow for pressure or vacuum can be traced by following the valve numbers given in the legend. With this arrangement of valves and piping, safety valves in the discharge line, immediately after the air cylinders, and vacuum breakers in the intake line, just ahead of the air cylinders, are necessary to prevent accidents, should the compressors be started with the valves closed. Globe valves equipped with rubber seat disks are used throughout.

The aftercooler, air receiver, air conditioning apparatus, and uniform flow valves are by-passed so that any equipment may be placed in or out of service without interruption.

Air entering the pressure chamber is evenly distributed throughout each compartment by means of diffusers. These consist of closed cylinders of perforated metal, lined on the inside with fine wire mesh, with the top and bottom of solid metal. Within each cylinder, supported from top and bottom, is the auxiliary copper coil heater. Under vacuum operation, additional air filters of the fabric type are placed inside the pressure chamber on the discharge side of the compartments and lock, so that no grit can be carried from the floor of the pressure chamber to the cylinders of the compressors. In addition, the return line from the pressure chamber to the compressor —that is, the compressor intake line during vacuum operation—is increased to a 4-inch diameter in order to reduce friction losses.

To prevent the transmission of vibration from the piping to the pressure chamber, the inlets of exhaust pipe lines are connected to the shell of the compartments by short pieces of rubber hose. This arrangement has also been followed on all service connections made to the pressure chamber, with the exception of the electrical connections.

Intake silencers are installed on both compressors; another silencer is installed, through which the compressed air passes immediately before entering either compartment; and exhaust silencers are placed on the air outlet of each compartment. Compressed air for the main lock also passes through a silencer in the lock.

The main pipe lines to each compartment from the air conditioning apparatus are covered with heat insulating material.

In addition to the main air line connection, an auxiliary compressed air supply from the power house of the Medical School is connected to the pressure chamber. This air supply is from steam driven compressors and is available at the pressure chamber at 30 pounds gauge. The piping arrangements are such that the reserve supply of air, after passing through a filter, can be passed through the air conditioning apparatus or through an independent heater or cooler. The connections of this line to the chamber are so arranged that the air flow, which is hand operated, can be controlled from inside or outside the chamber, but is at all times directly under outside control. Similarly, a reserve exhaust line is connected to the chamber, which is also under the same method of control. In the event of complete failure of the main and reserve supplies, provision is made on the piping of the reserve line for connection with portable com-

pressor units of local public service companies.

Service steam, brine, and electricity for the equipment are led from the supply lines to the School, which come direct from the power house.

Cooling water for the compressors and aftercoolers is so piped that water from the compressors can be run through the aftercooler or else each can have individual supplies.

All pressure gauges, heat regulator controls, temperature recording apparatus for the chamber, and control switches and pilot lights for the chamber lighting system are mounted conveniently in the engine room.

Operation

Experimental conditions require operation of the chamber with either one or both compartments. When both compartments are used, they may be at the same or different pressures, temperatures, and air flow. Pressures may be positive or negative; they cannot be positive in one compartment and negative in the other. Ventilation rates determine whether one or both compressors are to be operated.

The unloading device on the compressors is set so that machines will unload at approximately 2 pounds above the pressure that is to be maintained in either compartment of the chamber at any one time. Operating pressure in compartments is obtained by adjusting the balance of the unloading valves. The pressure is read directly from gauges on each compartment and also is recorded continuously on charts in the engine room.

When the chamber is under positive pressure, a safety valve on each compartment and on the lock is set slightly below the working pressure of the compressor. For measuring pressures less than atmospheric, mercury manometers are used.

Temperature conditions to be maintained in one or both compartments determine whether the heating or the cooling elements of the air conditioning apparatus should be in operation in order to obtain the necessary dew point temperature of the air.

Air flow is read directly from manometers in cubic feet per minute and is adjusted by means of uniform flow valves. To retain pressure conditions in the chamber should the air flow be interrupted for any reason, check valves Nos. 28 and 34 (Fig. 2) and quick-closing valves Nos. 35 and 39 are located in the main pipe line as shown. If the compressors should fail or if the diaphragm of the uniform flow valves should rupture, the check valves would close. Should the uniform flow valve stick, the unloading valve would automatically take care of any increase or decrease in flow. On the other hand, should the unloading valve stick so that it remained closed, the pressure would tend to build up to the pressure of the compressor and the safety valves would then open; if this valve should stick so as to remain open, or if its diaphragm should become ruptured, the pressure would fall. For this condition, the quick-closing valves are provided.

The methods of supplying air to operate the main lock under positive pressure are subject to the conditions of individual experiments. The air may come from the reserve supply line used to its pressure capacity; it may be led direct from the air conditioning

apparatus through valve No. 29 (Fig. 2); or it may be led from the compartments direct to the lock. Various combinations of these three methods are used. All three sources of supply join a common line in the lock.

In order to conserve pressure, it is essential that the large chamber doors close quickly during compression and decompression. The clamps on the doors are hand operated and keep the doors in such a position that they seal as soon as pressure is applied. A positive pressure of 1.5 pounds or a negative pressure of 3 inches of mercury compresses the rubber gasket sufficiently to open the clamps automatically, leaving the door free.

The lock is decompressed by exhausting through the reserve exhaust to the atmosphere. The main lock can be compressed and decompressed from within or from without. A continuous record is kept of pressure conditions in this lock whenever it is in operation.

The small mail lock on each compartment is hand operated. Air from each compartment is piped to its lock at a point between the lock door inside the compartment and the lock door on the outside. The pipe line is fitted with a quick-operating valve which can be opened to the compartment or to the atmosphere. When the compartment is under pressure, and the inside door of the lock is closed and the outside door open, material can be placed within the lock. The outside door is then closed and the valve opened to the compartment. This builds up a pressure in the lock equivalent to that in the compartment and allows the inner door to be opened and material removed. Material is passed out of the compartment by reversing the procedure. The door inside the compartment is closed, and the valve is turned to atmospheric pressure; the air within the lock then escapes, the pressure falls, and the outside door can be opened. By adding a valve with a weighted arm to the atmospheric side of the quick-operating valve, the mail locks can serve as decompression chambers for small animals when decompression has to be extended over a considerable period of time. These mail locks are also equipped with pressure gauges.

When pressure within a compartment is being lowered over a long period of time, ventilation can be maintained at a steady rate of flow by manipulation of the lever which controls the size of the orifice on the uniform flow valves.

To keep the air entering the chamber fresh and clean, careful attention to cylinder lubrication of the compressors is necessary; too much oil gives a very perceptible oil haze in the chamber. By means of an automatic oil feed to the cylinders, checked every twenty-four hours, the supply can be so regulated that this condition can be avoided without impairing the compressor cylinders and without using separators in the line.

In this installation, where the operating routine varies greatly with experimental conditions, attention is called immediately to any unfavorable condition in the chamber, or in the working of the equipment, by an annunciator alarm system operated by pressure control apparatus and temperature thermostats.

Thermostats which regulate the temperature of the cooling water leaving each compressor cylinder and after-

cooler are connected with this system. A rise of less than 10°F. in the temperature of this cooling water is indicated by the annunciator alarm. These thermostats are set by means of ordinary mercury thermometers located alongside.

An automatic pressure control is installed in the circulating pump circuit of the air conditioning apparatus. This pump has a differential pressure of approximately 30 pounds above the air pressure. Any loss of pressure in either the compressors or the pump, due to power failure or to any other cause, is transmitted to a control gauge, set within very narrow limits, which is also connected with the annunciator alarm. Loss of pressure at this point, if due to compressor failure, would not be apparent in the chamber, because check valves Nos. 28 and 34 and unloading valves Nos. 36 and 40 would close and ventilation would cease. Pressure drop in the chamber due to causes other than the failure of compressors is taken care of by automatic controls in each compartment which are also connected with the annunciator alarm.

Whenever the installation or any part of it is in operation, a daily log of the working of the equipment and of the chamber is kept.

CONTROL OF THE SILICOSIS HAZARD IN THE HARD ROCK INDUSTRIES. II. AN INVESTIGATION OF THE KELLEY DUST TRAP FOR USE WITH PNEUMATIC ROCK DRILLS OF THE "JACKHAMER" TYPE*

THEODORE HATCH
Instructor in Sanitary Engineering, Harvard University

GEORGE S. KELLEY
Mechanical Engineer, George J. Atwell Foundation Corporation, New York City

AND

J. WILLIAM FEHNEL
Chief Chemist, Laboratory of Industrial Hygiene, Metropolitan Life Insurance Company, New York City

INTRODUCTION

THE health hazard associated with exposure to atmospheres containing finely divided, silica bearing dust is well recognized. Silicosis ranks high as an industrial disease in certain industries or trades, among which may be mentioned mining and tunneling in rock containing free silica. An important source of dust in these industries is from rock drilling, which is done by high speed pneumatic drills. The holes are drilled by the rapid blows of the bit which shatter the stone, and finely divided particles of rock are blown out of the hole by the air stream that passes down the center of the drill steel. The rate of dust production is high since the speed of drilling may be greater than 100 feet a day. In confined spaces such as drifts and headings in mines and tunnels, therefore, it is readily seen that excessive dust concentrations may be encountered and that in the case of silica bearing rock, a serious health hazard exists. The investigations in the gold mines of South Africa (1), in the lead mines in Missouri (2), and elsewhere (3) (4) are well known, and the silicosis hazard associated with these mining operations is fully recognized.

Rock drilling is not confined to underground work, however, but is also used widely in open excavation for building foundations, subway cuts, and trench work, in quarries, and in many other cases where surface rock is removed. Since these operations are carried on in the open where wind currents serve to disperse the dust, a silicosis hazard has not in the past generally been associated with them. Smith (5, p. 39), however, has demonstrated that a real hazard exists. Her findings, based upon a study of 208 rock drillers, blasters, and excavators in New York City, showed that 118, or 57 per cent., had evidence of silicosis. Among the seventy-two men who

* A co-operative study from the New York Department of Labor, the Metropolitan Life Insurance Company, and the Department of Industrial Hygiene, Harvard School of Public Health.

Received for publication Oct. 28, 1931.

had worked only in open excavations, thirty, or 42 per cent., had ante-primary or more advanced stages of the disease. Among all those examined, the ante-primary stage was conspicuous after five years' exposure; ten years' exposure produced first stage silicosis; and second and third stages of silicosis were found in high proportion after twenty years.

These findings were corroborated by the results of the dust survey of several open rock excavation jobs in New York City by Fehnel (5, p. 69), who reports dust concentrations varying from 53 million to 17 billion particles per cubic meter of air at the breathing zone of the drill runners.

The recommendations (5, p. 81) of the Silicosis Committee, appointed to advise the New York Department of Labor on the preparation of a code to cover this hazard, were as follows:

1. Rock drilling, blasting, and excavating in New York City constitute a serious hazard to the health of the workers, owing to the constant exposure to silica dust, resulting in silicosis and tuberculosis. Remedial measures are urgently needed.
2. Efforts must be made immediately to improve markedly, by controlling the dust concentration, the conditions under which the men employed in these occupations are compelled to work.
3. Compensation should be granted by law for disability due to silicosis.

Following these studies and the report of the Silicosis Committee, a second committee[1] was appointed to investigate dust control equipment for use with rock drills and to formulate engineering specifications for its design and operation.

A dust trap in conjunction with an exhaust system had already been employed by Mr. Kelley on certain operations of the George J. Atwell Foundation Corporation, and preliminary tests by Mr. Fehnel had demonstrated its possibilities as a means of control for use with rock drills of the "jackhamer" type. The attention of the Advisory Committee was directed toward this device and the present paper is the report of an experimental study of it.

Description of Kelley Dust Trap

The Kelley trap consists of a metal chamber designed to enclose the drill steel at the rock surface. No attempt is made to secure a mechanical seal with the rock or between the trap and the drill steel. The dust is captured by an air stream as it wells up out of the hole, and is carried into an exhaust system to which the trap is connected. Any escape of the dust particles through the openings between the uneven rock surface and the trap or around the drill steel is prevented by the air seal produced by the inflowing air.

Unlike many previous attempts to capture the dust generated by rock drills, this device is not actuated by an ejector operated by the exhaust air from the drill. It is connected to an independent central exhaust system which may be designed to accommodate any number of drills and which is provided with a highly efficient dust collecting plant.

The trap, which is shaped very much like an inverted tin dipper, is illustrated in Figure 1. It is split to facilitate insertion and removal of the drill steel, and the two halves are connected

[1] Advisory Committee on Rock Drilling, Sand Blasting, and Rock Crushing.

y means of a spring hinge. A sim-
le catch keeps the trap closed during
peration. The hole through which
he drill steel passes is $1\frac{5}{8}$ inches in
diameter, and since the diameter of
the steel is $1\frac{1}{4}$ inches or less, free rota-
ion is thus permitted. The trap is
edly constructed of heavy metal
rder that it may stand up under the
h usage to which it is subjected in
ld.

FIG. 1.—Kelley trap for use with pneumatic rock drills.
A = trap in place; B = trap open to show method of enclosing drill steel.

Air is drawn through the trap and into the exhaust system by means of a side connection 2 inches in diameter. To provide flexibility of operation, the connection to the main suction system is made by means of flexible hose which may be in various lengths to accommodate different types of work.

Since the trap encloses completely the point of dust generation, efficient operation will be secured when the air velocity through the openings between the rock and the trap and around the drill steel is great enough to prevent the escape of dust particles, and when sufficient air motion is set up within the trap to carry away the large amount of material as it emerges from the hole. Experimentally, therefore, it is necessary to determine the total air flow through the trap required to produce this condition, the criterion being the dust concentration existing at the breathing zone of the drill runner. Tests of this nature have been carried out, and are described in the present paper.

EXPERIMENTAL STUDY

Purpose of Tests

The object of the investigation was to determine the minimum rate of air

had worked only in open excavations, thirty, or 42 per cent., had ante-primary or more advanced stages of the disease. Among all those examined, the ante-primary stage was conspicuous after five years' exposure; ten years' exposure produced first stage silicosis; and second and third stages of silicosis were found in high proportion after twenty years.

These findings were corroborated by the results of the dust survey of several open rock excavation jobs in New York City by Fehnel (5, p. 69), who reports dust concentrations varying from 53 million to 17 billion particles per cubic meter of air at the breathing zone of the drill runners.

The recommendations (5, p. 81) of the Silicosis Committee, appointed to advise the New York Department of Labor on the preparation of a code to cover this hazard, were as follows:

1. Rock drilling, blasting, and excavating in New York City constitute a serious hazard to the health of the workers, owing to the constant exposure to silica dust, resulting in silicosis and tuberculosis. Remedial measures are urgently needed.
2. Efforts must be made immediately to improve markedly, by controlling the dust concentration, the conditions under which the men employed in these occupations are compelled to work.
3. Compensation should be granted by law for disability due to silicosis.

Following these studies and the report of the Silicosis Committee, a second committee[1] was appointed to investigate dust control equipment for use with rock drills and to formulate engineering specifications for its design and operation.

A dust trap in conjunction with an exhaust system had already been employed by Mr. Kelley on certain operations of the George J. Atwell Foundation Corporation, and preliminary tests by Mr. Fehnel had demonstrated its possibilities as a means of control for use with rock drills of the "jackhamer" type. The attention of the Advisory Committee was directed toward this device and the present paper is the report of an experimental study of it.

Description of Kelley Dust Trap

The Kelley trap consists of a metal chamber designed to enclose the drill steel at the rock surface. No attempt is made to secure a mechanical seal with the rock or between the trap and the drill steel. The dust is captured by an air stream as it wells up out of the hole, and is carried into an exhaust system to which the trap is connected. Any escape of the dust particles through the openings between the uneven rock surface and the trap or around the drill steel is prevented by the air seal produced by the inflowing air.

Unlike many previous attempts to capture the dust generated by rock drills, this device is not actuated by an ejector operated by the exhaust air from the drill. It is connected to an independent central exhaust system which may be designed to accommodate any number of drills and which is provided with a highly efficient dust collecting plant.

The trap, which is shaped very much like an inverted tin dipper, is illustrated in Figure 1. It is split to facilitate insertion and removal of the drill steel, and the two halves are connected

[1] Advisory Committee on Rock Drilling, Sand Blasting, and Rock Crushing.

...y means of a spring hinge. A sim-...le catch keeps the trap closed during ...peration. The hole through which ...he drill steel passes is $1\frac{5}{8}$ inches in ...diameter, and since the diameter of ...he steel is $1\frac{1}{4}$ inches or less, free rota-...tion is thus permitted. The trap is ...ruggedly constructed of heavy metal ...n order that it may stand up under the ...rough usage to which it is subjected in ...the field.

FIG. 1.—Kelley trap for use with pneumatic rock drills.
A = trap in place; B = trap open to show method of enclosing drill steel.

Air is drawn through the trap and into the exhaust system by means of a side connection 2 inches in diameter. To provide flexibility of operation, the connection to the main suction system is made by means of flexible hose which may be in various lengths to accommodate different types of work.

Since the trap encloses completely the point of dust generation, efficient operation will be secured when the air velocity through the openings between the rock and the trap and around the drill steel is great enough to prevent the escape of dust particles, and when sufficient air motion is set up within the trap to carry away the large amount of material as it emerges from the hole. Experimentally, therefore, it is necessary to determine the total air flow through the trap required to produce this condition, the criterion being the dust concentration existing at the breathing zone of the drill runner. Tests of this nature have been carried out, and are described in the present paper.

EXPERIMENTAL STUDY

Purpose of Tests

The object of the investigation was to determine the minimum rate of air

flow through the dust trap necessary to keep the dust concentration at the breathing zone of the drill runner within the limits of hygienic safety. In order to obtain this information, it was necessary to establish the relation between the dust concentration and the rate of air flow through the hood over a range of air flow rates. Since a number of different drills varying in power, size of drill steel, and rate of dust production are used in excavation work, it was necessary to establish the correlation between dust concentration and air flow for a number of representative drills, in order to obtain an air flow specification that would care for maximum conditions.

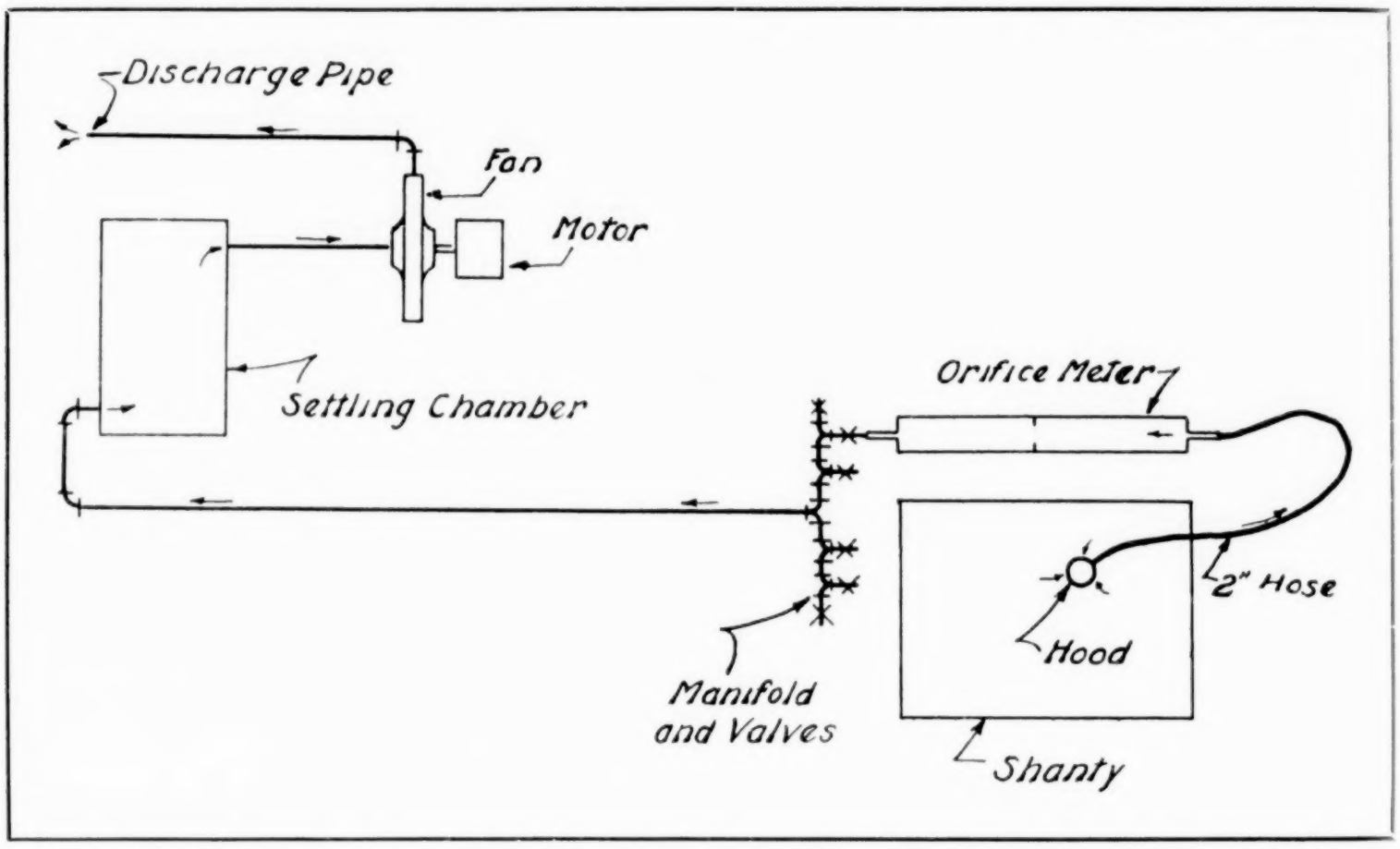

FIG. 2.—Layout of experimental dust control system for pneumatic rock drills. (Not to scale.)

Experimental Layout

The main tests were conducted on a foundation job on 59th Street near Seventh Avenue, New York City; the rock at this location is a medium-hard Manhattan schist. Subsequent check tests were conducted on the site of the new building for the Metropolitan Life Insurance Company, on Fourth Avenue between 24th and 25th Streets. For the investigation at 59th Street, the following layout was employed:

Drilling operations were carried on within a contractor's shanty 6 feet by 8 feet by 6 feet, 10 inches (average height). Large openings between the shanty and the uneven ledge were closed with boards, but no effort was made to render the structure tight since its purpose was simply to prevent dust dispersion by air currents, thus giving consistent results among the several tests.

The exhaust system is shown diagrammatically in Figure 2. A 2-inch flexible hose was attached to the dust trap and connected to the exhaust system through a standard orifice meter.

A tank connected in the line served as a sedimentation chamber in which large dust particles were removed. A centrifugal blower, considerably over capacity in size, provided the necessary air flow. Variation in air flow through the dust trap was obtained by adjusting the values in the manifold of the exhaust system.

Drills Used

Three standard drills of the jackhamer type were taken from field supplies and operated according to field practice (see Table 1). They represent the range in drill sizes found in building foundation work, and therefore include the operation with maximum requirements for dust control. Vertical holes having an average depth of 5 feet were sunk at an average rate of 14 feet, 7 inches an hour, using dry drilling in all cases. It was estimated that approximately 15 cubic feet of air per minute was discharged by the drill through the steel.

TABLE 1.—DRILLS USED FOR TESTS

MFR.	TYPE	STEEL	OPERATING PRESSURE
			lbs./sq.in.
I.R.	BCR-430	$\frac{7}{8}$ in.; hollow, hexagonal	75–85
I.R.	S-49	1 in.; hollow, hexagonal	75–85
I.R.	X-59	$1\frac{1}{4}$ in.; hollow, round	75–85

Dust Disposal

During the first test, the collected dust was discharged into the atmosphere at a point about 45 feet away from the shanty. Owing to the danger of atmospheric pollution about the shanty, this dust was eliminated very largely in subsequent tests simply by directing a water spray into the discharge pipe.

The exhaust system employed on the excavation for the Metropolitan Life Insurance Company building included dust collecting equipment consisting of a preliminary settling chamber followed by cloth filters of the screen type. This plant effectually removed the dust from the air discharged about 8 feet above the street level. The high efficiency of dust collection, together with the dilution and dispersion by air currents, was sufficient to prevent dangerous dust pollution from this source in the excavation or at the street level.

Dust Measurements

Dust sampling was done with the Greenburg-Smith impinger (6) in accordance with the standard procedure. Since this instrument has been used in several surveys of the hard rock industries, the results of this study may be compared with those obtained in other closely allied industries.

For all tests except No. 1, cutting operations were carried on for thirty minutes before sampling was started, in order that the dust concentration in the shanty might approach a condition of equilibrium or saturation (7, p. 84). Two samples were then taken, each over a period of fifteen minutes.

Air Flow Measurements

Measurements of air flow were made by means of a standard 2-inch thin-plate orifice inserted in a 5-inch line,

the pressure drop across the orifice being measured by an ordinary vertical water manometer. In calculating the rates of air flow, the fundamental orifice formula (for an incompressible fluid) was used, with the proper

TABLE 2.—DUST COUNTS, RATE OF AIR FLOW, AND RATE OF DRILLING: TEST DATA OBTAINED AT 59TH STREET, NEW YORK

MACHINE	TEST NO.	ORIFICE DROP[1]	TEMPERATURE	AIR FLOW	DUST COUNT		DEPTH DRILLED	AV. RATE OF DRILLING PER HOUR
					A and B[2]	Av.		
		in.	*°F.*	*cu.ft./min.*	*millions/cu.ft.*		*ft./in.*	*ft./in.*
BCR-430	1	3.20	59	97.5	2.98			
					2.12	....	.....	....
	2	2.07	59	78.5	1.02			
					0.69	0.85	.....	....
	3	1.64	50	70.0	1.19		66[3]	
					0.95	1.07		....
	4	1.13	53	58.0	1.87			
					1.81	1.84	.....	....
	5	0.49	55	38.2	4.93			
					4.95	4.94	.....	13/3
S-49	6	4.02	59	112.0	5.87			
					4.17	5.02	14/10	....
	7	2.44	59	85.3	1.36			
					1.215	1.29	12/3	....
	8	1.88	51	74.8	0.85			
					1.21	1.03	15/7	....
	9	0.77	53	47.8	1.28			
					0.95	1.12	18/8	....
	10	1.19	53	59.5	1.19			
					0.95	1.07	16/6	15/7
X-59	11	3.98	53	109.0	1.87			
					2.00	1.93	15/4	....
	12	6.22	..	134.0	1.45			
					1.47	1.46	15/–	....
	13	1.16	47	58.7	5.47			
					3.24	4.35	16/1	....
	14	2.85	..	92.2	3.66			
					2.95	3.30	17/2	....
	15	1.95	56	76.2	2.70			
					2.60	2.65	12/8	....
	16	0.50	58	38.6	2.98			
					3.17	3.07	12/–	14/9
Av.....	..	....	55	.....	....	....	.....	14/7

[1] Orifice was cleaned after each test, except Nos. 1 to 4, inclusive.

[2] Sample 1A was taken during the first thirty minutes of the test, and sample 1B during the second thirty minutes. In all other tests the samples were taken during the second thirty minutes, each over a period of fifteen minutes.

[3] Total for five tests.

J. I. H.
Feb., 1932

temperature corrections. The readings were subject to some error on account of change in air density when conveying dust and on account of change in the orifice coefficient due to dust settling out at the orifice. Since these changes are opposite in effect, however, one tends to balance the other.

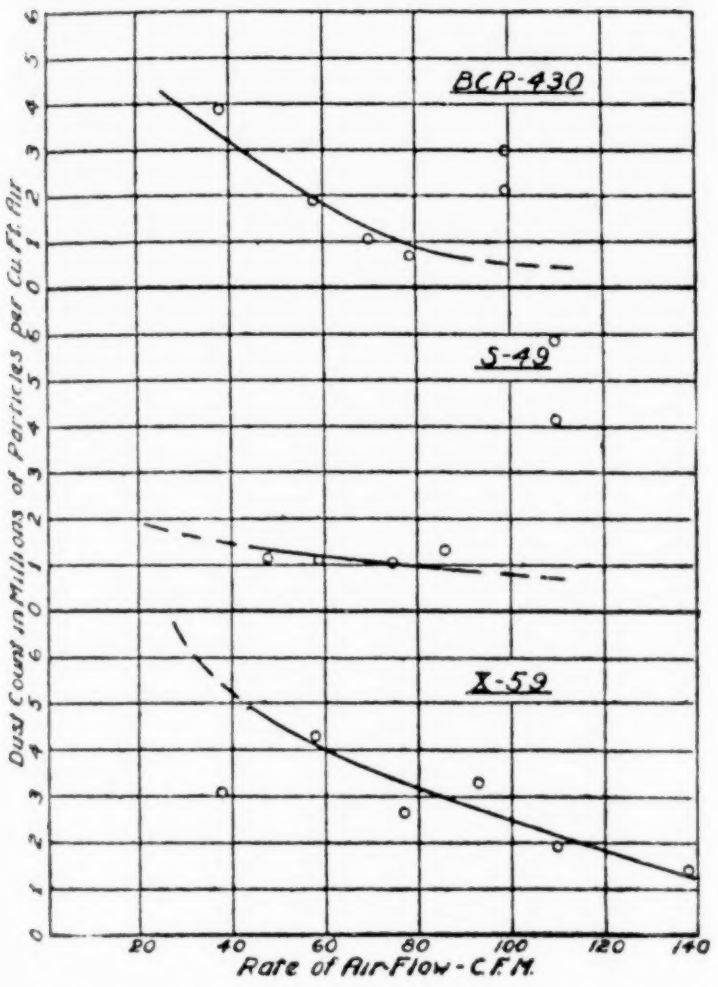

FIG. 3.—Relation between dust concentrations and rate of air flow through trap, for three representative drills.

DATA AND DISCUSSION OF RESULTS

Relation between Dust Concentration and Air Flow

Curves showing the relation between dust concentration at the breathing zone of the operator and rate of air flow through the hood for the three drills tested are given in Figure 3. They were prepared from the data presented in Table 2.

Although there is considerable fluctuation in the dust concentration values, indicating low correlation, there is a significant trend which suggests an increase in dust concentration with decreasing air flow. This increase seems to be more rapid at low rates of flow, and the general shape of the curves is similar to that obtained from studies in hood design in connection with other industrial processes (7, p. 86).

The curves show no striking differences between the three machines except for the slightly higher dust counts associated with the larger drill, the X-59. This may be owing, in part, to the higher exhaust velocity of the drill stirring up dust deposits on the floor, or it may be indicative of more rigorous conditions of dust production. In any event, the results show that the relationship for the X-59 drill may be taken as representative of maximum conditions.

Required Air Flow through Trap

In order to specify the minimum air flow requirement for the trap from these results, it is necessary to adopt a standard of permissible dustiness. If the trap is to be used with jackhamers operating on all kinds of rock, then a single air flow specification, designed to protect all drill runners, would obviously have to be based upon a safe concentration of the most hazardous dust. Present knowledge concerning safe concentrations of various dusts is not sufficiently extensive, however, to permit this. For Barre, Vt., granite, with a free silica content of from 30 to 40 per cent., a standard having a lower limit of 10 million particles per cubic foot of air[2] has been proposed (8). In the South African gold mines,

[2] Determined by the impinger method.

where the free silica content is 80 per cent. and over, a threshold concentration of less than 1 mg. per cubic meter is stated to be safe (9). This is approximately equivalent to from 300 to 400 particles per cubic centimeter of air, or from 8.5 to 11.3 million particles per cubic foot, as determined by the konimeter (10). For Sydney sandstone (85 to 95 per cent. free silica) a standard of 200 particles per cubic centimeter,[3] or 5.7 million particles per cubic foot, was advocated (11).

method) may be taken for purposes of establishing the minimum air flow requirement for the Kelley trap.[4]

From the curve for the X-59 drill in Figure 3, it is seen that an air flow of 60 cubic feet per minute is necessary to keep the dust concentration below this value.

Check Tests

The air flow specification of 60 cubic feet per minute was checked in a series of tests conducted during the excavat-

TABLE 3.—DUST CONCENTRATIONS DURING ROCK DRILLING ON FOUNDATIONS FOR METROPOLITAN LIFE INSURANCE COMPANY BUILDING

TEST NO.	MACHINE	LOCATION	DUST CONTROL	AIR FLOW THROUGH TRAP	DUST COUNT	AV. RATE OF DRILLING PER HOUR
				cu.ft./min.	*millions/cu.ft.*	*ft.*
1	4 S-49 3 BCR-430	Center of circle made by seven drills	Exhaust	68	5.6	....
2	4 S-49 3 BCR-430	Same	None	..	614.5	....
3	.....	General air in excavation at noon; blasting during sampling	.....	..	2.2	....
4	S-49	Inside shed	Exhaust	60	1.8	22.0
8	BCR-430	Same	Exhaust	58	2.6	23.0
8a	BCR-430	Outside; same time as #8	.....	..	3.6	....
10	X-59	Inside shed	Exhaust	53	3.9	11.3
10a	X-59	Outside; same time as #10	.....	..	3.5	....

In Manhattan Island stone, the free silica content was found by Fehnel (5, pp. 74–75) to vary from 0.01 to 84.3 per cent. On the basis of a comparison between the New York conditions and those associated with the above-mentioned standards, it appears that a working standard of safety of 5 million particles per cubic foot of air (by the impinger

[3] Determined by Owens' jet dust counter.

ing for the new Metropolitan Life Insurance Company building on

[4] It should be pointed out that in setting this figure, no attempt was being made to establish a standard in the medical sense. It was adopted tentatively merely as a criterion for determining an engineering specification. Since the completion of this investigation the committee has recommended to the New York Department of Labor a standard of 10 million particles per cubic foot of air. The air flow requirements, based upon a maximum dust concentration of 5 million particles per cubic foot of air, will therefore be on the safe side.

Fourth Avenue, between 24th and 25th Streets. Dust concentrations at the breathing zone of the drill runner were determined with the Kelley trap in place and operating with a rate of air flow of approximately 60 cubic feet per minute.

In the first test, seven drills were operated on the circumference of a

The remaining tests were conducted inside a shanty similar to the one employed at 59th Street, and the same procedure was followed. The results of this series of tests are presented in Table 3 and require very little comment. The dust concentrations found are all satisfactory and the results constitute a very good check on the 59th

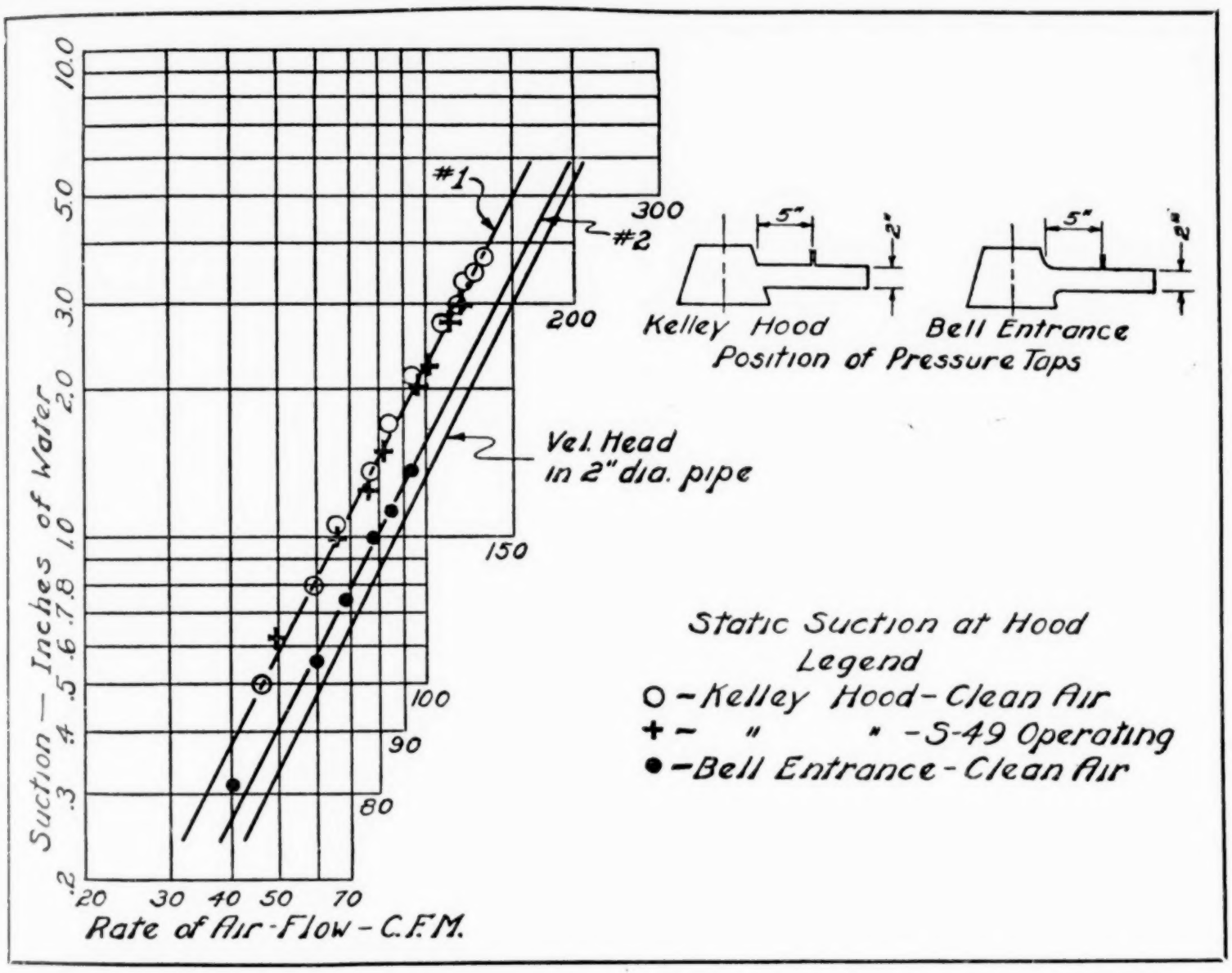

FIG. 4.—Static suction in side connection to Kelley trap for various rates of air flow.

circle about 6 feet in diameter, with the impinger set up in the center. Dust determinations were made both with and without the hoods in place. In the latter case, through our oversight, the traps were allowed to remain near the drills; the dust concentration reported is therefore somewhat lower than it would have been, had there been no ventilation.

Street investigation. From these studies, it appears that under conditions of jackhamer operation such as were encountered on these two jobs, Kelley traps, when operating at 60 cubic feet per minute, will serve to keep the dust concentration at the breathing zone of the drill runners below 5 million particles per cubic foot of air.

Static Suction Required

In practice, the operating requirement of a dust exhaust hood is commonly specified in terms of the static suction to be maintained in the branch connection, rather than in terms of air flow through the hood. This value has been determined for the Kelley trap over a considerable range in rate of air flow, and the relationship is shown by curve 1 in Figure 4. For a flow of 60 cubic feet per minute, the static suction is found to be 0.8 inch, water gauge. Curve 2 shows the possibility of reducing the suction requirement by improving the shape of the entrance.

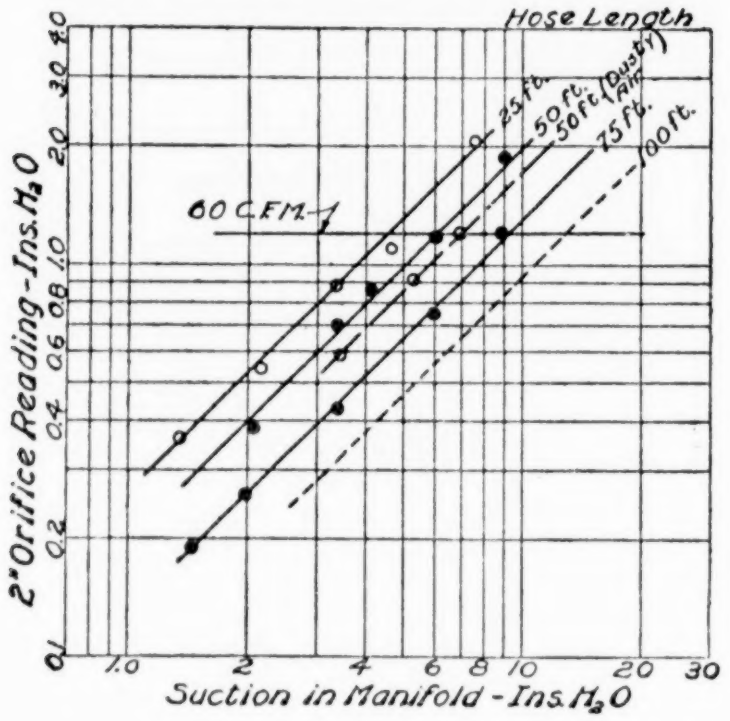

FIG. 5.—Static suction in manifold for various rates of air flow and various lengths of hose.

Since in practice the traps are connected to the suction manifolds by various lengths of 2-inch flexible hose, considerable pressure loss occurs in the hose; from the point of view of design, therefore, it is desirable to know the value of the static suction to be maintained in the manifolds. This has been determined for various lengths of hose, for different rates of flow, and for clean and dusty air. The results are shown in Figure 5. For a rate of air flow of 60 cubic feet per minute and for hose lengths of 25, 50, 75, and 100 feet the static suction developed in the manifold was estimated from the curves in Figure 5 and is presented in Table 4.

These figures may be used for the purpose of design or for checking the operation of field installations.

TABLE 4.—STATIC SUCTION IN MANIFOLD FOR A FLOW OF 60 CUBIC FEET PER MINUTE AND DIFFERENT LENGTHS OF 2-INCH FLEXIBLE HOSE: DRILLS OPERATING

HOSE LENGTH	STATIC SUCTION IN MANIFOLD
ft.	*in. H_2O*
25	3.5
50	7.0
75	10.5
100	14.0

SUMMARY

An investigation was made of the dust collecting efficiency of the Kelley trap for use with pneumatic rock drills of the jackhamer type. Dust concentrations at the breathing zone of the drill runner were correlated with the rate of air flow through the hood. Adopting a standard of permissible dustiness of 5 million particles per cubic foot of air, the rate of air flow necessary to reduce the dustiness below this value was found to be 60 cubic feet per minute. A number of check tests with the trap operating at this rate showed that it was satisfactory and that it could be used as the basis for design of dust control equipment for rock drills of the jackhamer type.

Static suction requirements at the hood and in the suction manifold, using four different lengths of 2-inch hose, were determined for various rates of air flow.

We acknowledge with gratitude the advice and assistance received from members of the Committee on Rock Drilling, Sand Blasting, and Rock Crushing, the New York, Department of Labor, the Metropolitan Life Insurance Company, George J. Atwell Foundation Corporation, and Mr. I. R. Loss of the General Electric Company.

BIBLIOGRAPHY

1. Watkins-Pitchford, W.: The Silicosis of the South African Gold Mines, and the Changes Produced in It by Legislative and Administrative Efforts. This Jour., 1927, *9*, 109.
2. Higgins, E., Lanza, A. J., Laney, F. B., and Rice, G. S.: Siliceous Dust in Relation to Pulmonary Disease among Miners in the Joplin District, Missouri. U. S. Bur. Mines, Bull. 132, 1917.
3. Lanza, A. J., and Childs, S. B.: Miners' Consumption. U. S. Pub. Health Bull. No. 85, 1917.
4. Harrington, D., and Lanza, A. J.: Miners' Consumption in the Mines of Butte, Montana. Preliminary Report of an Investigation Made in the Years 1916–1919. U. S. Bur. Mines, Tech. Paper 260, 1921.
5. Silicosis among Rock Drillers, Blasters, and Excavators in New York City, Based on a Study of 208 Examinations. This Jour., 1929, *11*, 37.
6. Katz, S. H., Smith, G. W., Myers, W. M., Trostel, L. J., Ingels, M., and Greenburg, L.: Comparative Tests of Instruments for Determining Atmospheric Dusts. U. S. Pub. Health Bull. No. 144, 1925.
7. Hatch, T., Drinker, P., and Choate, S. P.: Control of the Silicosis Hazard in the Hard Rock Industries. I. A Laboratory Study of the Design of Dust Control Systems for Use with Pneumatic Granite Cutting Tools. This Jour., 1930, *12*, 75.
8. Russell, A. E., Britten, R. H., Thompson, L. R., and Bloomfield, J. J.: The Health of Workers in Dusty Trades. II. Exposure to Siliceous Dust (Granite Industry). U. S. Pub. Health Bull. No. 187, 1929.
9. Mavrogordato, A.: Contributions to the Study of Miners' Phthisis. So. African Inst. Med. Res., Pub. No. 19. Johannesburg, 1926.
10. Mavrogordato, A.: The Value of the Konimeter—Being an Investigation into the Methods and Results of Dust-Sampling as at Present Practised in the Mines of the Witwatersrand. *Ibid.*, Pub. No. 17. Johannesburg, 1923.
11. Badham, C.: An Investigation Concerning Ventilation and the Sandstone Dust Present in the Air of Certain Sewer Tunnels under Construction at North Shore, and in Other Sandstone Workings. Studies in Indust. Hyg., No. 2, Rep. Dir.-Gen. Pub. Health, New South Wales, for 1924, Section I.-C, Indust. Hyg., p. 52. Sydney, 1926.

WILLIAM FRANCIS DEARDEN, M.R.C.S. (Eng.), L.R.C.P. (Lond.), D.P.H. (Vict.), J.P.

Sorrow is ours in referring to the loss of an Assistant Editor of This Journal in the person of William Francis Dearden who died somewhat suddenly on Sept. 15, 1931, in the Salford Royal Hospital. He passed away while still full of vigor and enthusiasm for his work. He was born on March 22, 1863; educated at Bolton High School and Owens College, Manchester, he qualified in 1885, and took the diploma in public health of the Victoria University in 1889.

He started in general practice and was appointed certifying factory surgeon for his district, a post which determined his life's work. Subsequently he became medical officer of health to the Manchester Port Sanitary Authority; but his main interest always lay in the influence exerted by occupation upon health. Working in Manchester he turned naturally to study the cotton textile industry, for he was essentially a Lancashire man and desired to give of his best to his own people. The knowledge he acquired was called upon from time to time by the Home Office, and led to his selection in 1927 as Milroy Lecturer to the Royal College of Physicians, when he dealt with "Health Hazards in the Cotton Industry" (see This Jour., 1927, *9*, 371, 453, 488). These lectures and his contributions on the same subject to the international encyclopedia on "Occupation and Health" will be standards for reference for years to come. His article on the accommodation of bargemen (This Jour., 1925, *7*, 215) to which his attention was drawn through his work as port medical officer led to improved quarters being provided.

Dearden took a leading part in the activities of the Certifying Factory Surgeons Association which he did much strengthen and consolidate; he was a regular attendant at professional gatherings and international congresses; and was a member of the Permanent International Committee for the Study of Occupational Diseases established by the International Labour Office. Keenly active himself, Dearden's personality inspired activity in others and the desire to search out facts and to draw deductions. He was never content to accept existing evils as inevitable and necessary.

This Journal and the cause of Industrial Hygiene have lost a strenuous supporter and an ardent friend with the passing of W. F. Dearden.—*E. L. Collis.*